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Grid-tied and stand-alone hybrid solar power system for desalination plant

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ABSTRACT

This paper presents results on simulation, optimization and control of hybrid solar based energy system to power a desalination plant. The principal objective is 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. The results of the baseline or the actual power system from the grid are compared with 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 system. The results show that the solar PV/grid/inverter power system offers the best performance compared to PV/diesel generator/battery/inverter. The total energy from the hybrid grid tied solar system is used to meet the AC load of the desalination plant with almost no excess electricity and power shortage. The proposed hybrid power system for the desalination plant is sustainable, economically viable and environmentally friendly: high renewable fraction (47.3%), low excess power (0.15%), low levelized cost of energy (90 $/MWh), and low CO_2 gas emissions (264.25 kg CO_2/MWh).

1. Introduction

Micro grid power systems use different types of renewable energy resources (wind, solar, biomass, hydro), energy generators powered with fossil and alternative and renewable fuels; energy storage devices; loads for residential, commercial and industrial applications; and power conditioning units such as inverters and rectifiers as shown in Fig. 1. The micro grid energy system can be connected to the utility grid or can operate separately off grid as stand-alone power system. The locally controlled micro grid power system provides more independence from the grid, a backup to the utility grid and security of the energy supply in case of emergency caused by major storms and natural disasters, offers more reliability of the energy supply and reduces the transmission losses.

Several studies can be found in the literature on the use of micro grid power systems for different applications [1–7]. Simulation, modeling and optimization using HOMER software and Simulink [8–13] were also used to identify the optimal off-grid options. The focus of this study is the use of micro-grid energy system to power desalination plants. The problem of fresh water shortage due to the environmental impacts, population growth and the increase in water consumption has accelerated the development of new desalination technologies. Different desalination technologies are used for seawater treatment: thermal (multi-stage flash distillation MSF, multiple effect distillation MED and thermal vapor compression TVC), mechanical (evaporation: mechanical vapor compression MVC, and filtration: Reverse Osmosis (RO)), electrical (selective filtration: electrodialysis ED), and chemical (exchange: ion exchange IE). Seawater desalination like other water treatments technologies requires the use of energy to produce water. The seawater desalination treatment process is energy intensive. The energy required depends on the technology employed, design of the plant, quality (salinity) and temperature of the feed water and the quality of the produced water. In multi-stage flash MSF, the process operates at a top brine temperature between 90 and 110 °C. The total electrical equivalent energy required by the MFS is between 19.6 and 27.3 kWh/m^3 [14]. For the Multiple effect distillation MED, where the brine temperature varies between 64 and 70 °C, the total electrical requirement varies between 14.5 and 21.4 kWh/m^3. For the MVC distillation technology, the total electrical requirement is between 7 and 12 kWh/m^3 while for the TVC distillation technology, the energy requirement is about 16.3 kWh/m^3 [14]. For the membrane distillation processes, the energy consumption depends on the salinity of the feed water and the recovery rate. For the Reverse Osmosis (RO), the main energy requirement is for pressuring the feed water. The water must be

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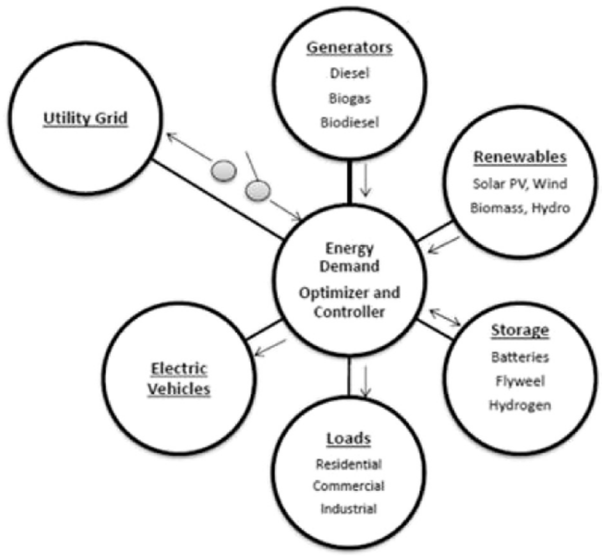

Fig. 1. Schematic of micro grid power system.

forced from the salty feed of the membrane to the purified water side of the membrane. The average energy consumption depends on the size of the facility and ranges from 3.7 to 8 kWh/m^3. For the electrodialysis ED desalination technologies, the electrical consumption ranges from 0.7 and 5.5 kWh/m^3 [14] depending on the salinity. New methods and strategies (enhance system design, high efficiency pumps, energy recovery, advanced materials, renewable energy system, etc.…) are needed to reduce the energy requirements for these desalination technologies. The power cost in desalination process may account for 30–60% of the operational costs. A small variation in the cost of power rates impact the cost of treated water.

Fossil fuel was the primary fuel used to power the desalination plants. New energy systems using renewable energy resources (solar, wind, biomass, and biofuels) can be used as alternative to the conventional fossil fuel based power systems. A desalination plant powered by renewable energy systems is more sustainable solution to the water shortage problem (use of renewable resources – no depletion of natural resources; clean energy systems – reduce GHGs emissions; reduce the operational costs – use the natural resources). The use of renewable energy systems in remote area will be a good solution due to the absence of grid to power the desalination plants. Heba et al. [15] performed a simulation and modeling study to size the renewable energy system used for Reverse Osmosis desalination system. Three power systems were considered PV-wind-battery system, wind –battery and a stand-alone PV system. The results showed that the PV-wind-battery based power system was more economically more practicable with a minimum net present cost (NPC) and a minimum levelized cost of energy (LCOE) of $327/MWh. Tang et al. [16] used an optimal operation method to design island micro grid to power desalination plant using wind/PV/Diesel generator/battery power system. The island micro grid in a certain district was taken as an example to verify the effectiveness of the proposed optimal method. The results provided the theoretical and technical basis for the optimal operation of the island micro-grid. In this study a hybrid Photovoltaic (PV)-fuel cell power system using an electrolyzer for hydrogen generation was designed and tested. The system was used to power a desalination plant using Reverse Osmosis (RO) technology. Said Touatia et al. [17] performed a modeling study using hybrid Photovoltaic (PV)-fuel cell power system integrated with an electrolyzer for hydrogen generation. The system was used to power a desalination plant using Reverse Osmosis (RO) technology. The hybrid system was able to generate power to meet the energy demand of the desalination plant and the excess power from the PV system to produce hydrogen through the electrolyzer. The hydrogen is compressed and stored in tank for later use when no solar radiation was available. Darwish et al. [18] tested solar energy systems (Concentrated Solar Power CSP and solar PV systems) to run different types of desalination technologies. The results revealed that PV-RO system has the highest specific capital cost, among the considered systems, because of the expensive storage of the electric energy in batteries, and the fact solar energy supply lasts about one third of the day. Currently, renewable-powered desalination capacity represents less than 1% of the world's desalination capacity [19]. Most of the renewable-powered desalination plants are based on RO technology (62%), followed by MFS and MED [19]. Solar PV is the most (43%) dominant renewable energy source used for desalination technologies, followed by solar thermal and wind [19]. Solar PV-based desalination system is considered one of the strongest options for renewable energy powered desalination but the levelized cost of energy (LCOE) is still high for an off grid or stand-alone renewable energy system. Previous desalination studies outlined in more details the Reverse Osmosis (RO) applications (prospect and challenges) [20–22], the integration of renewable energies such as solar and wind for RO desalination systems (system performance and cost analysis) [23–25] and the capacity building strategies and policy for desalination using renewable energies [26].

The principal objective of this study is to design a renewable energy system to meet the desired electric load for the desalination plant in Sharjah, United Arab Emirates with high renewable fraction (increase the penetration of renewable resources for the energy mix), low excess power (reduce the dissipated dump load of energy), low levelized cost of energy and with low environmental impacts (reduce the carbon foot print).

2. Hybrid power system modeling

Two renewable hybrid energy systems to power the desalination plant are investigated in this study. The first hybrid power system, shown in Fig. 2, consists of a PV array, grid and a converter. The second hybrid off grid power systems shown in Fig. 3 consists of PV array, Diesel generator, battery bank and a converter. For the baseline case the desalination plant will be connected directly to the grid without solar PV array.

The use of grid-tied solar PV system will allow to save money by lowering the equipment and installation cost of the power system. The grid-tied solar PV system does not need the use of batteries and other stand-alone equipment. This will help to reduce the capital and maintenance of the power system. The solar panels will often generate more electricity than what is consumed by the load. The excess electricity can be put onto the utility grid instead of storing this energy in batteries. This will help to reduce the losses during the charging and discharging of the battery used in an off-grid power system. The grid-tied solar PV system will help to generate extra revenue by selling back the extra power generated by the PV panel. This will help to reduce the levelized

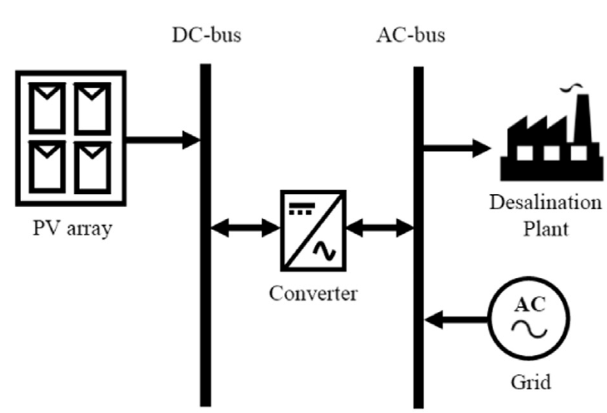

Fig. 2. Schematic of hybrid grid-tied solar PV/inverter power system.