Design and Cost Analysis of Hybrid Renewable Energy for Water Desalination in Remote Areas

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Abstract: ***A large proportion of the world's population lives in remote areas that have no access to fresh water sources and not connected to the electrical grid at the same time. The aim of this paper is to investigate the possibility of replacing diesel power generation, which is the major source for green house gas emission, with hybrid renewable energy systems for seawater reverse osmosis desalination in remote areas. The hybrid energy system based on renewable energy technologies with back up generation from fossil fuel improves the system reliability. Various renewable and non renewable energy sources, energy storage methods and their applicability in terms of cost and performance are discussed. The cost of energy is the main parameter used to compare economic performances of the systems. A software tool, Hybrid Optimization Model for Electric Renewable (HOMER) is used for the analysis. Based on simulation results, it has been found that renewable energy sources will replace the conventional energy sources and would be a feasible solution for cleaner generation of electric power for reverse osmosis desalination at remote and distant location.***

Keywords: Energy, Desalination, optimization, Homer.

1. Introduction

Water scarcity is one of the world's most severe problems. It is expected that in 2025 almost 3.5 billion people, 48% of the world's population, will have an insufficient water supply [1]. At the same time, about one third of the world's population, 2 billion people, is not connected to an electrical grid [2]. State of the art purification in desalination technologies can convert almost any water into potable water but they do require energy, mainly in the form of electricity. Thus, the water problem can also be seen as an energy problem since seawater, brackish water or freshwater of unknown quality are abundantly. Egypt has been the victim of recurrent droughts and water shortage [3]. This problem varies from place to another especially in the coastal and arid areas where the use of conventional energy (fossil fuels, electricity) is costly or not available.

Reverse Osmosis (RO) desalination processes have been the technology of choice as a result of recent technological developments in the process engineering. The average costs of product water have decreased significantly. The specific energy requirement is significantly low [4]. Renewable energy sources (RES), such as photovoltaic and wind turbine generator, provide a realistic alternative to engine-driven generators for electricity generation.
Applications of Hybrid Renewable Energy Systems (HRES) are usually more reliable and lest costly than the systems that use a single source of energy [5-9].

RO desalination powered by HRES represents an ideal solution for providing freshwater to coastal and arid areas with high renewable potential and having access to the sea or brackish water [4]. In addition to that, use of HRES help in reducing fossil fuel consumption levels and the consequent effect of carbon dioxide and other green house gases [10]. In this pre-feasibility study, modeling and optimization of HRES to meet the electrical requirements for an existing Sea Water Reverse Osmosis (SWRO) desalination plant powered with conventional diesel generator (DG) has been done. This HRES consists of Photovoltaic array (PV), Wind turbine (WT) and converter accompanied with battery and DG for emergency backup considering uncertain availability of these weather dependent sources. A case study is given based on the practically available data with analysis using HOMER (means Hybrid Optimization Model for Electric Renewable) computer software [11-12]. As HOMER does both optimization and sensitivity analysis, it makes easier to evaluate many possible system configurations of the large number of technology options and the variation in technology costs and availability of energy resources. The paper is organized as follows: Description of SWRO plant and measuring the electrical load profile is discussed in section 2. Study area and renewable energy resources are discussed in section 3.Energy hybrid system model and economic analysis with HOMER Software are given in section 4. The results obtained from Homer simulation is discussed in section 5.

2. Description of SWRO Plant and Load Pattern

For the analysis, a case study of an existing SWRO desalination plant erected in 2010 and powered with DG has been selected. Scheme of RO process is shown in figure 1.

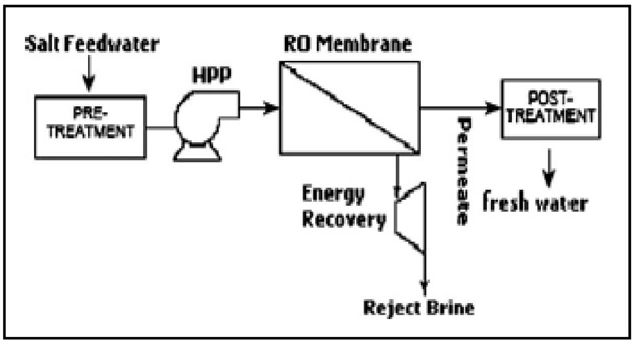


Figure 1: Scheme of RO process

The plan consists of one RO unit with 600 m3/d capacity. The unit fresh water production cost is 0.95 $/m3. Technical specifications of RO unit are shown in table 1.

Table 1: SWRO Unit Technical Specifications

Item	*Specification*
Feed Concentration,(ppm)	39000
Number of stages	1
Number of passes	1
Pressure vessel number	8
Membrane number per vessel	6
Membrane type	Filmtec SW30HRLE-400
Energy recovery device	PX-300, ERI
Recovery ratio, %	30
Feed pressure,(bar)	63
Permeate flow rate,(m3/d)	600
Permeate concentration,(ppm)	150
Daily operating hours, (h)	22

In RO desalination systems, energy is a major consideration. Power consumption by the system which includes power for feed sea water pumping, high pressure pumping (HPP), High pressure (HP)booster, and chemical treatment dosing could be calculated using the following equation [4],

Ppump.=0.02778*P*Q/ η%

Where:
- Ppump (kW) is the Power consumed by pump,
- Q(m3/s) is the Flow rate ,
- P(bar) is the Feed pressure and
- η% is the Net efficiency of feed pump.

Table 2: Energy requirement for SWRO plant

Pumps	*No*	*P,bar*	*Q,m^3/h*	*η%*	*$P_{cons.}$ kW*	*kWh/m^3*
intake	1	3	120	80	12.5	0.46
Feed	2	3.8	45	80	11.88	0.44
Dosing	5	#	#	80	0.75	0.03
HPP	1	65	30	80	67.71	2.48
HP Booster	1	3	60	80	6.25	0.23
Distribution	1	4	50	0.8	6.95	0.25
Total					106.05	3.88

Table 2 summarizes the total energy requirement for the plant which equal to 106 kWh on the base of 22 operating hours daily. an auxiliary load (lightning, air conditions,….) is equal to 5 kWh .in order to make the assumption of load calculation more realistic, 15% noise are added in the model for daily and hourly loads, respectively (figure 2).

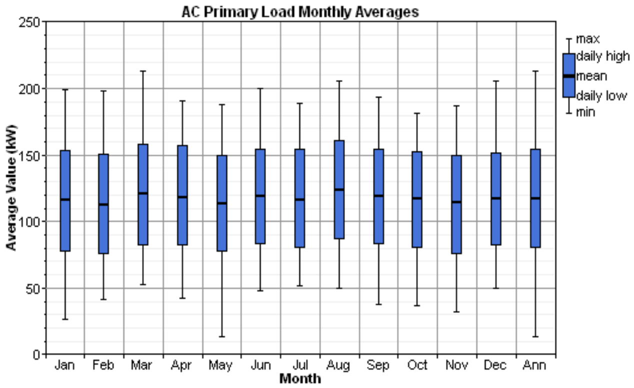


Figure 2: Monthly average load pattern

3. Study Area and Renewable Resources

The SWRO plant located in Red sea coast of Egypt (latitude: 25.06, longitude: 34.9). Data estimations about solar and wind resources with load prediction are necessary for complete system simulation and assessment. In the present work, the climatic data are obtained from the metrological station of NASA [13]. The monthly wind speed variation, the monthly clearness index and the daily radiation are shown in Figure 3 and 4.

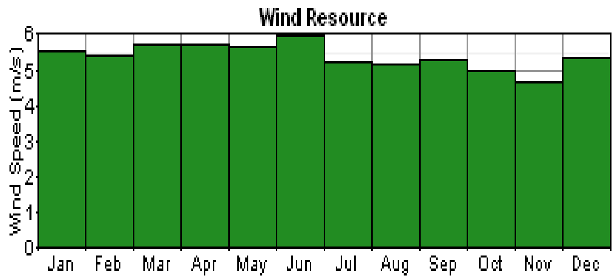


Figure 3: Monthly average wind speed variation

The annual average wind speed and the annual average solar radiation are 5.4 m/s and 6.12 (kWh/m2/d) respectively.

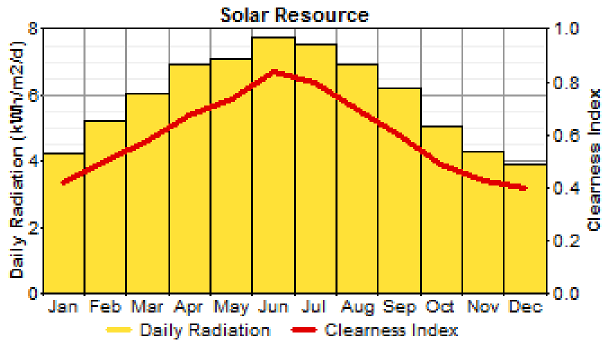


Figure 4: Average monthly solar radiation

HOMER software requires several data to calculate the output of the wind turbine and the photovoltaic panel each hour of the year. These parameters are summarized in Table 3; some of these parameters are approximated.

Table 3: Parameters required by software

Parameters	*Value*
Weibull distribution factor	2
Autocorrelation factor	0.85
Hours of peak wind speed	15
Diurnal pattern strength	0.25
Altitude, m	50
Anemometer height, m	10
Surface roughness length, m	0.01

4. Energy model and economic analysis with HOMER

Model definition in HOMER including: load, resources, economic, constrains, controls and other component that have been used is given in Figure 5.

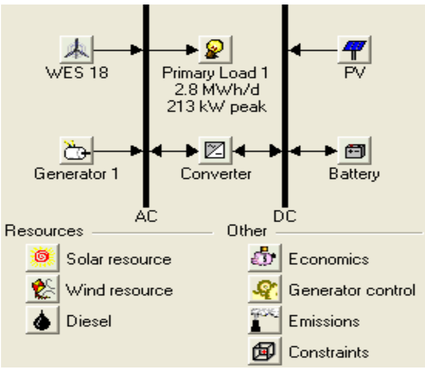


Figure 5: Renewable energy hybrid system

HOMER is a modeling tool that facilitates design of standalone electric power systems where the levelized cost of energy (COE, $/ kWh) is given by:

Where: Cann,tot is the total annualized cost ($/yr), Etot is the total annual load served (kWh/year), The total net present cost (CNPC) is HOMER's main economic output. All systems are ranked corresponding to the net present cost, and all other economic outputs are calculated for the purpose of finding the net present cost.

HOMER computes the total NPC using the following equation:

Where CRF is the capital recovery factor, i is the interest rate (%) and Rproj is the project lifetime (yr).The CRF expressed by equation:

In this work different hybrid options were analyzed to get an optimized hybrid system sizing. The initial capital cost, replacement cost, maintenance cost and lifetime of each component are shown in Table 4.

Costs and equipment performances data have been assumed by market surveys and by literature [14-15]. The project life time has been considered to be 20 year and the annual interest rate has been taken as 6%.

Table 4: Parameters required by software

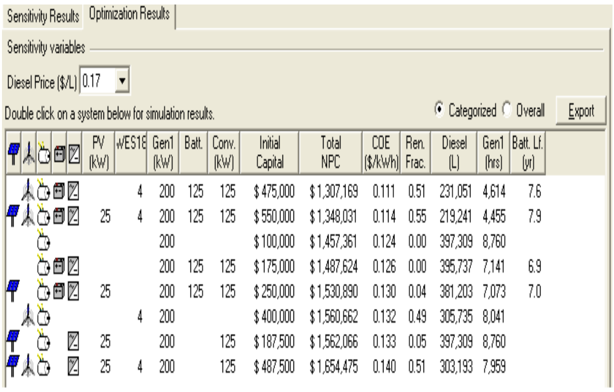
Characteristics	*DG*	*PV module*	*WT*	*Battery*	*Converter*
Model	Typical	Typical	WES 18	Surrette 4ks25p	Typical
Power	200 kW	1 kW	80 kW	7.6 kWh	1 kW
Life time	15000 h	20 yr	20 yr	3 yrs	20 yrs
Price,$	100000	3000	75000	500	100
Replacement,$	90000	3000	75000	450	100
O&M	0.2 $/hr	10 $/hr	750	0.5 $/yr	10 $/yr

5. Simulation Results and Discussions

HOMER simulates system configurations with all of the combinations of components that were specified in the component input. HOMER performs hundreds or thousands of hourly simulations (to ensure best possible matching of demand and supply) and offers a list of feasible schemes ranked on the basis of the NPC. The strategy taken in this simulation is to ensure the power generator provide enough power to meet the demand.

5.1 Optimal Energy Options

HOMER provides the simulations results in terms of optimal system analysis. The optimization results of the renewable hybrid system (Figure 5) are shown in Figure 6. HOMER posts a list of feasible configurations for this project. They are enumerated in the order of more to least reliable (from top to bottom). An optimal system is defined as a solution for hybrid system configuration that is capable of meeting the load demand of SWRO plant with lowest COE.


Sensitivity Results | Optimization Results

Sensitivity variables

Diesel Price ($/L) 0.17

Double click on a system below for simulation results. Categorized Overall Export

PV (kW)	WES18	Gen1 (kW)	Batt.	Conv. (kW)	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)	Batt. Lf. (yr)
	4	200	125	125	$ 475,000	$ 1,307,169	0.111	0.51	231,051	4,614	7.6
25	4	200	125	125	$ 550,000	$ 1,348,031	0.114	0.55	219,241	4,455	7.9
		200			$ 100,000	$ 1,457,361	0.124	0.00	397,309	8,760	
		200	125	125	$ 175,000	$ 1,487,624	0.126	0.00	395,737	7,141	6.9
25		200	125	125	$ 250,000	$ 1,530,890	0.130	0.04	381,203	7,073	7.0
	4	200			$ 400,000	$ 1,560,662	0.132	0.49	305,735	8,041	
25		200		125	$ 187,500	$ 1,562,066	0.133	0.05	397,309	8,760	
25	4	200		125	$ 487,500	$ 1,654,475	0.140	0.51	303,193	7,959	

Figure 6: Categorized optimization results.

From the simulation result, three different power systems have been considered and compared in terms of their performance. The first is Wind-Diesel-Battery Hybrid system configuration. This system is the best optimal power solution for SWRO plant with lower COE estimated at around 0.111 $/kWh for a diesel price of 0.17 $/L. The system components are: 4 wind turbines, and 25 PV modules, 125 batteries, 125 kW converter and 200kW diesel generator. In this scenario SWRO plant is supplies with wind and diesel energy together. This system uses 51% renewable energy in which 51% electricity comes from wind source (667,499 kWh/yr) and 49% electricity comes from Diesel generator (628,908 kWh/yr) with zero values for an annual capacity of shortage and unmet load respectively (Figure 7). The annual electricity production from the optimal hybrid system is 1,027,841 kWh.

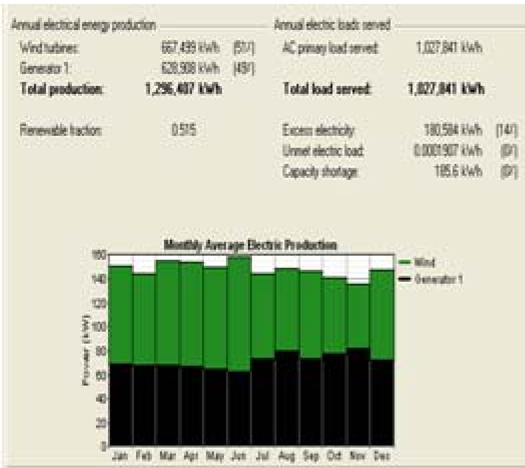
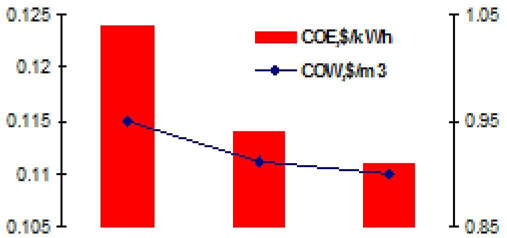


Figure 7: Energy yield from the optimal system

The second optimum power solution is the Wind-PV-Diesel-Battery Hybrid system with estimated COE at around 0.114 $/kWh. Diesel power generation is the less optimality system with estimated COE at around 0.124 $/kWh which is 11.7% higher than optimal system COE.

5.2 Water Cost

Energy is usually the major component cost over the useful service life of SWRO plants. Its contribution to the water production cost can range from about 30% to 50% depending on energy cost. In this study, the unit production cost of fresh water (COW) from the originally proposed SWRO plant (section 2) is 0.95$/m3 with specific energy consumption estimated at 3.88kWh/m3 in which all energy requirements comes from conventional diesel generator.



	Diesel generator	Hybrid PV-Wind-Diesel-	Hybrid Wind-Diesel-Battery
COE,$/kWh	0.124	0.114	0.111
COW,$/m3	0.95	0.911	0.900

Figure 8: COW and COE for different energy options

The comparison of COW and COE for different energy options as shown in Figure 8. It can be noticed that the optimal Wind-Diesel-Battery Hybrid system is the most economic solution and can improve both of COE and COW with 10.5% and 5.3% respectively as compared to conventional diesel generator.

6. Conclusions

In present work, by using the software tool HOMER, different scenarios are studied for the coverage of the desirable electric requirements for an existing SWRO desalination plant powered with conventional diesel generator. The simulation results indicate that the Wind-Diesel-Battery Hybrid system is the most economically feasible option. Specifically, In comparison to only diesel electricity generation system, this system presents 14% better load coverage, 10.5% lower energy cost, 5.3% lower water cost and lower emission level. These results indicate a potential solution for Egypt's energy and water problem in the direction of an environmental-friendly financially efficient solution based on RES.

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Author Profile

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