Optimization of Renewable Power System for Small Scale Seawater Reverse Osmosis Desalination Unit in Mrair-Gabis Village, Libya

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Abstract— Potential of renewable power system for small scale seawater reverse osmosis desalination unit in Mrair-Gabis village, Libya is evaluated. HOMER optimization model is used to evaluate the different possible configuration options for supplying the electrical load. This includes sizing, simulation and economic estimation of the system based on 0.25$, 0.5$ and 0.75$ diesel prices. At 0.25$ diesel price, the Gen/Battery option is the best economically. At 0.5$ and 0.75$ diesel prices, solar energy takes a good share when solar radiation intensity is more than 6.7 kWh/m^2 and 4.6kWh/m^2 respectively and the PV/Gen/Battery combination becomes more feasible. Wind energy on the other hand does not seem to be cost effective in the sensitivity analysis because the wind potential is limited at the particular site of study.

Keywords— power system, HOMER, reverse osmosis seawater desalination, Mrair-Gabis-Libya

I. Introduction

RENEWABLE power systems could introduce a cost-effective substitute to expensive grid extensions in isolated areas of the world. Renewable energy hybrid systems look into the process of selecting the best configuration of components and their sizing with appropriate operation strategy to provide efficient, reliable and cost effective power source. Many studies had been carried out in this area and the findings from these studies have been very helpful in developing the field such as Amal et al. (2010)[1], Ahmad Agus Setiawan et al. (2008)[2], Elhadidy and Shaahid (2007)[3], Eyad Hrayshat (2008)[4], Getachew and Palm (2009)[5], Giatrakos et al. (2007)[6], Himria et al. (2008)[7], Jeremy Lagorse et al. (2007)[8], Joseph et al. (2008)[9], Dalton, et al. (2007)[10].

The major inputs for HOMER simulation are a suggested load profile of small-scale reverse osmosis water desalination load at a remote location on the Libyan coast, local renewable resources, and diesel price. The simulation program is used for optimum design of the integrated system and also for managing the energy supply and the energy storage. The diesel generator remains in the system to act as a backup generator for extended periods of low renewable energy input or high load demand. Such systems are usually installed in location where fuel supplies are expensive and unreliable, or where strong incentives for the use of renewable energy exist, Al-Alawi and Islam (2003) [11].

II. Area of Study

Mrair-Gabis village was selected as a village which has no electric power supply from the national grid, the village is located about 250 km west of Benghazi city with latitude and longitude of 30°5'N , 19°8’E respectively, and nearest city is Ajdabya which is 50 Km away. The climate in this region is the Mediterranean Sea; the ambient temperature ranges between (-5–45) ^{o}C. The population of the village is counted as 39 families totaling of 350 inhabitances scattered in an area of about 15 km^2. This population is living either in houses or huts, in addition to a school for the students from the first to the ninth grade. The main activity of this village is livestock pasturing and agricultural, Ekhlat et al. (2007) [12]. The General Electric Company of Libya electrified the village in 2003 using PV isolated systems for each house. The central way of energy production was omitted firstly due to the geographical nature of the site; secondly to get rid of having a distribution network and the problems arises with any fault in the network and/or other load problems in spite of the main advantage of it, namely the reduced storage capacity required, Ekhlat et al. (2007) [12].

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III. Methodology

The HOMER software, NREL's micro power optimization model, can evaluate a range of equipment options over different constraints to optimize small power systems. Such way of analysis could help in the planning of rural electrification projects. The results could then serve as a starting point for the design of individual installations. HOMER simulated the operation of thousands of different system designs, with and without a backup generator. It is then capable of identifying the most economic system in terms of load size and other variables.

HOMER's capabilities offer an excellent option for modeling and testing these scenarios. The model first runs an hourly simulation of every possible configuration of system types. The speed of processing these simulations allows for the evaluation of thousands of combinations. This hourly simulation also provides improved accuracy over Statistical models that typically evaluate average monthly performance of a system. HOMER also models the partial load efficiency of diesel generators. This more accurately simulates the lower efficiency of a generator when it is not operating at full capacity. [13]

After running the simulations, HOMER sorts the feasible combinations in order of increasing net present cost. This cost is the present value of the initial, component replacement, operation, maintenance, and fuel costs, and then lists the optimal configuration, defined as the one with the least net present cost, for each system type. The sensitivity analysis then repeats this optimization as user-defined factors, such as fuel price, load size, and varied resource quality. HOMER can perform a sensitivity analysis by accepting multiple values for a particular input variable such as the average load [13].

A. Load Demand

The SWRO load is assumed to operate for 10 hours from 8:00 to 18:00 with a full load of 8.5kW in addition to 1 hour before 8:00 and 1 hour after 18:00 of 1 kW for preparation and closing as shown in Fig 1. This load profile was estimated to produce around 10 m^3/day of fresh water. The production of water is supposed to be the same along the year; therefore there is no change in the load profile. In reality, the size and shape of the load profile may vary from hour to hour and from day to day. Hence, on a daily and hourly basis a 15% noise level has been added to the calculated load in order to randomize the load profile and make it more realistic. This has scaled up the annual peak load to 16 kWp, as can be observed in Fig 3

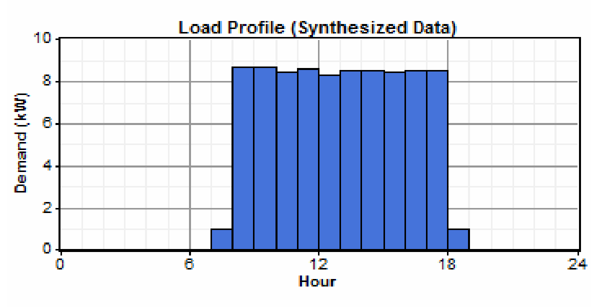

Fig 1: SWRO Daily Load Profile

B. Solar Resource

Mrair-Gabis village located at 30°5'N latitude and 19°8'E longitude. Solar radiation data for this region was retrieved from NREL website [14]. The annual average solar radiation for this area is 5.62kWh/m^2/d. Fig 2 shows the solar resource profile over a one-year period.

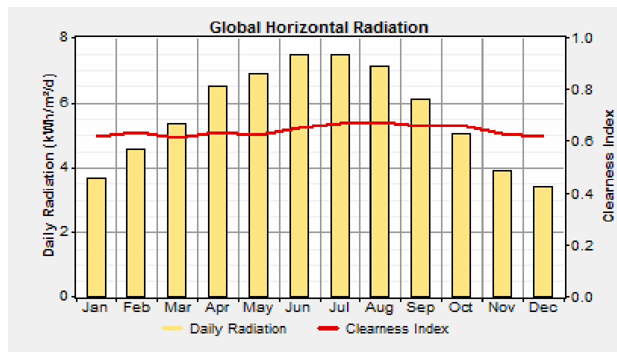

Fig 2: Averages Solar Radiation Profile for Mrair-Gabis

C. Economics

A real annual interest rate of 2% was assumed. The real interest rate is equal to the nominal interest rate minus the inflation rate. The appropriate value for this variable depends on current macroeconomic conditions, the financial strength of the implementing entity, and concessional financing or other policy incentives. HOMER converted the capital cost of each component to an annualized cost by amortizing it over its component lifetime using the real discount rate.

D. Equipment Considered

A diagram for the hybrid system setup is illustrated in Fig 3. Other input information to the calculation program is summarized in Table 1. This information includes the sizes and prices of the hybrid setup components which have been obtained from different resources.

Table 1 Power system Components Considered in this study

Component	Size kW	Capital Cost ($)	Replacement Cost($)	O&M Cost($)	Life time
PV Panels	1	8000	7000	0	25 years
Wind turbine	7.5	28500	24500	200	20 years
Generator	1	1000	800	0.05/h	15000h
Trojan L-16 Batteries		275	275	3	1075 h
Inverter	1	700	700	0	15 years

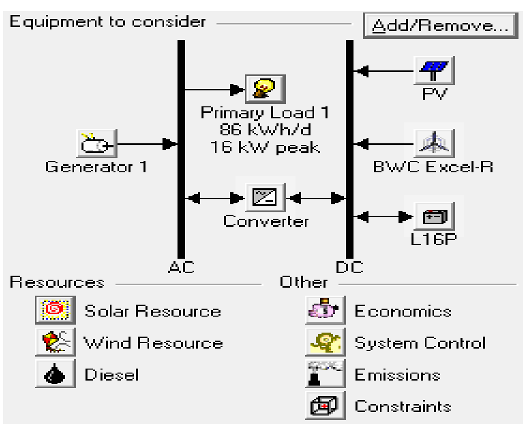

Fig 3: HOMER Diagram for the Hybrid system Setup

E. Photovoltaic Panels

Photovoltaic panels were specified with capital and replacement costs of 8000$ and 7000$ respectively, this cost includes shipping, tariffs, installation, and dealer mark-ups. Some maintenance is typically required on the batteries in a PV system, but very little is necessary for the panels themselves. A derating factor of 80% was applied to the electric production from each panel. This factor reduces the PV production by 20% to approximate the varying effects of temperature and dust on the panels. The panels were modeled as fixed and tilted south at an angle equal to the latitude of the site.

F. Wind Turbine

The wind turbine has a capacity of 7.5kW. Its initial cost is 28500$ and its replacement at 24500$. Annual operation and maintenance cost is 200$. Its hub and anemometer is located at 20 meter height. The life time of the turbine is estimated to be 20 years. The average monthly wind speed as obtained from NASA Surface Meteorology and Solar Energy web site is shown in Fig 4.

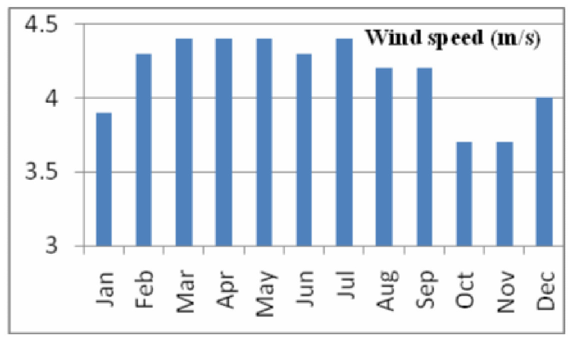

Fig 4: Monthly wind speed

G. Diesel Generator

Among all the different information that manufacturers provide on the broad range of generators, the partial load efficiency is one of the most important parameter that HOMER requires when simulating this component. The Operation and maintenance costs for the generators are listed per hour of operation. HOMER calculates the duration that the generator must run in a year and finds the total operating costs from this value. For this study the generator is AC and the capital cost was considered on basis of 1000$ per 1Kw and its replacement costs 800$. The operation and maintenance is 0.05$ per hour. The lifetime of the generator is estimated at 15000 operating hours. A sensitivity analysis on the price of diesel fuel also included. This price can vary considerably based on region, transportation costs and current market price. Diesel is priced at 0.25, 0.50, and 0.75 per liter in this study.

H. Batteries

Trojan L-16P type was chosen because it is a popular and inexpensive option. HOMER considered from 0-70 of these batteries. The valve regulated lead acid battery is rate at 6 V and has a capacity 360 Ah. Initially cost for one battery is 275$. The replacement batteries will cost another 275$. The operation and maintenance cost add further 3$ with a minimum life time of 8 years.

I. Inverter

The efficiencies of the inverter and rectifier were assumed to be 90% and 85% respectively for all sizes Considered. The simulations were done for each system switching the power between the inverter and the generator. Both devices were not allowed to operate in parallel. Initial and replacement cost for the converter is 700$, with no cost for operation and maintenance.

IV. Results And Discussion

A. Optimization Results

The calculation run takes into account the range of minimum to maximum values for the global solar radiation and wind speed at three fuel prices. In the case when the renewable resources are at their minimum values and the fuel price is maximum, in Table 2 the diesel generator/battery looks economically the best solution while the fourth system in the list gives promising renewable share with no significant increase in the cost of energy but with much higher capital cost.

Table 2: Optimization Results for minimum renewable resources and maximum fuel price

Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 3.41 | Wind Speed (m/s) 3.7 | Diesel Price ($/L) 0.75

Double click on a system below for simulation results. ⦿ Categorized

PV (kW)	XLR	Gen. (kW)	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen. (hrs)	Batt. Lf. (yr)
		10	22	5	$ 19,550	12,299	$ 259,667	0.423	0.00	11,049	3,667	10.0
	1	10	22	6	$ 48,750	11,502	$ 273,312	0.445	0.12	9,662	3,428	10.0
8		10	14	6	$ 82,050	10,307	$ 283,287	0.462	0.22	8,867	3,418	9.0
8	1	10	30	8	$ 116,350	9,335	$ 298,593	0.487	0.35	7,284	2,740	8.6
		16			$ 16,000	17,399	$ 355,684	0.580	0.00	14,191	4,380	
8		14		4	$ 80,800	14,770	$ 369,164	0.602	0.13	11,738	4,365	
	1	16		4	$ 47,300	17,094	$ 381,043	0.621	0.02	13,237	4,298	
8	1	14		4	$ 109,300	14,481	$ 392,020	0.639	0.21	10,965	4,242	
39	5		66	16	$ 483,850	3,967	$ 561,296	0.915	1.00			10.0
71			70	16	$ 598,450	1,692	$ 631,476	1.029	1.00			10.0

For the case when the renewable resources and the fuel prices are at average values as in Table 3 the generator/battery still economically the best however it can be seen in the second combination that the PV gives 39% renewable share for only slight increase in the cost of energy (COE) and 60% renewable energy share in the fourth combination for very small increase in the COE and the net present cost and very much less operating cost.

When the renewable resources are at maximum and the fuel price is minimum the Gen/Battery still the cheapest and we can see from Table 4 that renewable energy can take an important share.

Table 3: Optimization Results for average renewable resources and fuel price

Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 5.62 | Wind Speed (m/s) 4.16 | Diesel Price ($/L) 0.5

Double click on a system below for simulation results. ⦿ Categorized

PV (kW)	XLR	Gen. (kW)	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen. (hrs)	Batt. Lf. (yr)
		10	22	5	$ 19,550	9,567	$ 206,331	0.336	0.00	11,055	3,693	10.0
8		10	30	9	$ 88,550	6,565	$ 216,715	0.353	0.39	6,791	2,532	8.9
	1	10	22	7	$ 49,450	8,749	$ 220,262	0.359	0.17	9,180	3,316	10.0
8	1	10	50	11	$ 123,950	5,257	$ 226,577	0.369	0.60	4,291	1,449	8.4
		16			$ 16,000	13,851	$ 286,420	0.467	0.00	14,191	4,380	
8		14		5	$ 81,500	11,313	$ 302,361	0.493	0.25	10,773	4,324	
	1	16		4	$ 47,300	13,529	$ 311,436	0.508	0.05	12,893	4,248	
28	1		66	16	$ 281,850	2,083	$ 322,526	0.526	1.00			10.0
8	1	14		6	$ 110,700	10,961	$ 324,699	0.529	0.34	9,776	4,088	
35			70	16	$ 310,450	1,692	$ 343,476	0.560	1.00			10.0

Table 4: Optimization Results for maximum renewable resources and minimum fuel price

Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 7.48 Wind Speed (m/s) 4.4 Diesel Price ($/L) 0.25

Double click on a system below for simulation results. Categorized

PV (kW)	XLR	Gen. (kW)	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen. (hrs)	Batt. Lf. (yr)
		10	22	5	$ 19,550	6,822	$ 152,736	0.249	0.00	11,058	3,710	10.0
	1	10	14	7	$ 47,250	6,428	$ 172,755	0.282	0.19	9,074	3,413	8.6
8		10	26	9	$ 87,450	4,481	$ 174,936	0.285	0.47	6,116	2,462	9.5
8	1	10	38	12	$ 121,350	3,556	$ 190,778	0.311	0.68	3,532	1,297	8.4
		16			$ 16,000	10,303	$ 217,155	0.354	0.00	14,191	4,380	
8		14		5	$ 81,500	8,422	$ 245,925	0.401	0.29	10,354	4,261	
	1	16		4	$ 47,300	10,215	$ 246,741	0.402	0.07	12,713	4,221	
21	1		50	16	$ 221,450	1,768	$ 255,960	0.417	1.00			10.0
8	1	14		7	$ 111,400	8,230	$ 272,071	0.443	0.39	9,237	3,969	
28			54	16	$ 250,050	1,376	$ 276,909	0.451	1.00			10.0

B. Sensitivity results

Looking at the graphical sensitivity results gives a different view for the results; it shows the whole range of the solar radiation versus the whole range of wind speed at the minimum, average and maximum diesel prices as shown in Figs 5-7 respectively.

In Fig 5 when the diesel price is minimum the Gen/battery is always the winner but when the diesel price is average as in Fig 6, the PV/Gen/Battery combination becomes more feasible at more than 6.7kWh/m2/day. The combination PV/Gen/Battery at maximum diesel price becomes the best when solar radiation more than 4.6kWh/m2/day as in Fig 7.

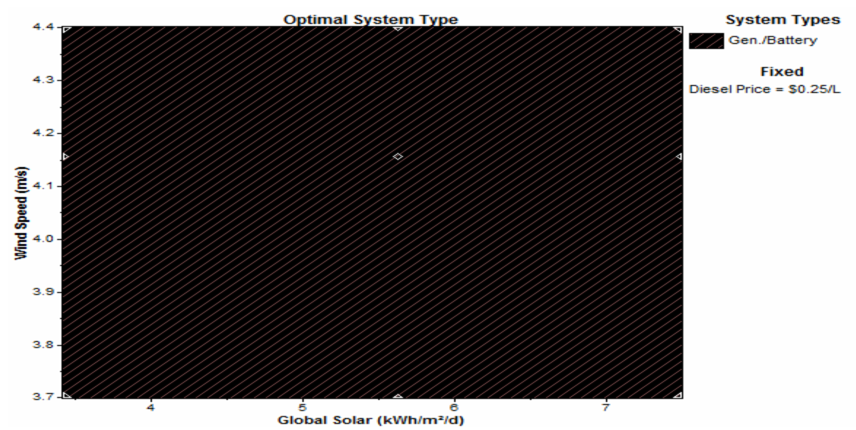

Fig 5: Sensitivity Results In Terms of Wind Speed and Global Solar Radiation with Diesel Price of $ 0.25

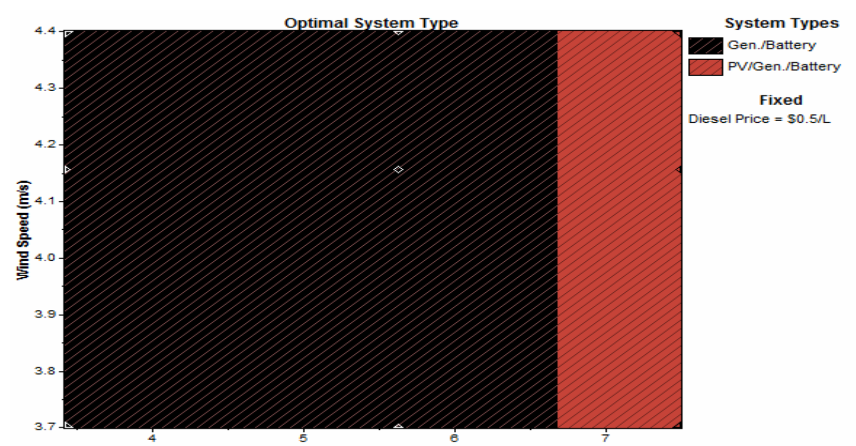

Fig 6: Sensitivity Results with Diesel Price of $ 0.5

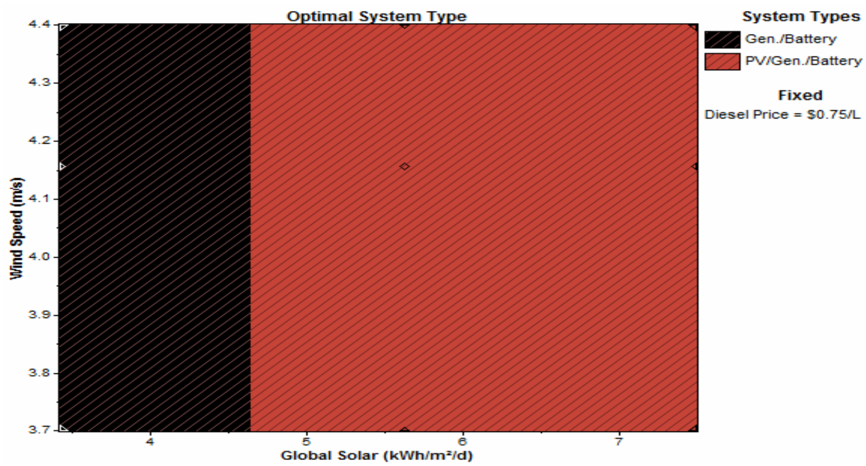

Fig 7: Sensitivity Results with Diesel Price of $ 0.75

V. Conclusion

Looking at the results, at minimum diesel price, the Gen/Battery option is always the best economically. At medium and high diesel prices 0.5$ and 0.75$, solar energy takes a good share when solar radiation intensity is more than 6.7 kWh/m^2 and 4.6kWh/m^2 respectively. Wind energy on the other hand does not seem to be cost effective in the sensitivity analysis because the wind potential is limited at the particular site of study. In addition to the economic and practical diesel generator drawbacks, considering the diesel emissions make the renewable options more feasible. Renewable resources also provide an independency of the national grid and oil resources in cases of wars and natural disasters.

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