Potential of Renewable System Powering a Mosque in Libya

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Abstract:- This paper presents a techno-economic analysis of a hybrid renewable system powering a remote mosque in Libya. Daily energy consumption profile for the four seasons is estimated based on a medium size mosque. In Libya, spring and autumn weather conditions are not as extreme as winter and summer; this decreases the load demand during these seasons. Therefore, summer and winter weather conditions are used as the basis where peak energy demand is expected because air-conditioning and heating loads are dominant. Winter electrical load is found to be the highest. HOMER software tool was used to determine the optimum size and specifications of renewable power system. When solar and wind are at their minimum values (4.32 kW/m^2/d, 3.79 m/s) and the fuel price is assumed as a maximum (0.75$), the most economically power system is PV/Gen/Battery with total net present cost (NPC) of 184094$, cost of energy (COE) of 0.478 $/kWh, and renewable fraction (RF) of 31%. When solar, wind and fuel price are assumed at average values of 6.34 kW/m^2/d, 4.81 m/s, and 0.5$, the optimal solution is also PV/Gen/Battery with (NPC) of 147485$ and (COE) of 0.383 $/kWh, and (RF) of 33%. When the solar and wind are assumed at maximum values of 8.06 kW/m^2/d, 6.02 m/s, and the fuel price is assumed minimum (0.25$), the most feasible economically system is still PV/Gen/Battery with (NPC) of 119311$ and (COE) of 0.310 $/kWh, and (RF) of 29%. The excess electricity from the hybrid renewable power system during spring and autumn can be sold to the utility or used for other applications. This will enhance the feasibility of renewable power systems at remote mosques.

Keywords: power system, hybrid renewable, HOMER, remote mosque, Alkufra – Libya

1 Introduction

Libya is an oil exporting country located in the middle of North Africa, with 6 million inhabitants distributed over an area of 1,750,000 Km^2. So, there are many villages and remote areas located far away from the national network. Economically these areas cannot be connected to the grid, owing to its small population, and the small amount of energy required. In the past these facts dictated the use of diesel generators as a source of power supply.

The use of solar and wind energy have been introduced in a wide applications due to its convenience use and being economically attractive in many applications. Many studies had been carried out in this area and the findings from these studies are very helpful in developing the field [1-10]. The proposed project is a mosque located on the highway 250 km from “Alkufra city” towards “Ejdabya city” and with latitude and longitude of 24°17'N, 23°15'E respectively.

The mosque is commonly a simple rectangular, walled enclosure with a roofed prayer hall. Figure1 illustrates the isometric of the mosque, typical mosques design in which the basic design elements are emphasized.

HOMER is an optimisation model which simulates various energy sources system configurations and sorts them on the basis of net present cost (NPC). HOMER firstly assesses the technical feasibility of the energy sources system (i.e. whether the system can satisfy the electrical and thermal loads and any other constraints imposed by the user). Secondly, it estimates the NPC of the system, which is the total cost of installing and operating the system over its lifetime. HOMER models every system configuration by performing an hourly time-step simulation of its operation for a one year period. The available renewable power is calculated and is compared to the required electrical load where the energy sources system is assessed as satisfying demand, any excess electricity is then spread to other secondary demands. If demand is not assessed as satisfied, an alternative supply, either by diesel or grid generation, is sought to fill the deficit. While HOMER’s 1-h time step is small enough to capture most of the statistical variability of the load and fluctuating renewable resources, it does not slow computation excessively.

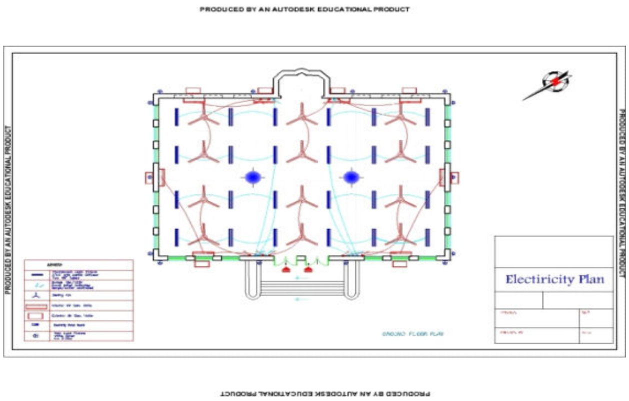

Fig. 1 Isometric element of the mosque

2 Assumptions And Model Inputs

The difference in the weather conditions and the solar time have led to four different load profiles as shown in figures 2-5. The loads of summer and winter seasons were calculated and shown in Tables 1-2.

Table 1 Summer electrical load

Electrical items	No of unit	Power (kW)	Total power (kW)
Fan	12	0.067	0.80
AC	8	0.75	5.97
water pump	1	1.5	1.50
Auxiliary loads (External lighting)	14	0.02	0.28
Auxiliary loads (internal lighting)	24	0.04	0.96
Total			9.51

Table 2 Winter electrical load

Electrical items	No of unit	Power (kW)	Total power (kW)
pump	1	1.5	1.5
space heater	8	0.75	5.97
water heater	1	2	2
Auxiliary loads (External lighting)	14	0.02	0.28
Auxiliary loads (internal lighting)	24	0.04	0.96
Total			10.71

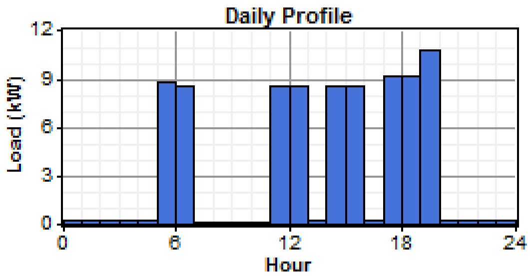

Fig. 2 Winter season load

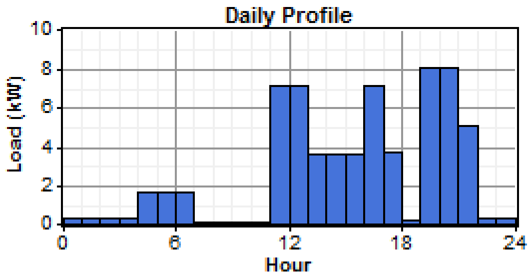

Fig. 3 Summer season load

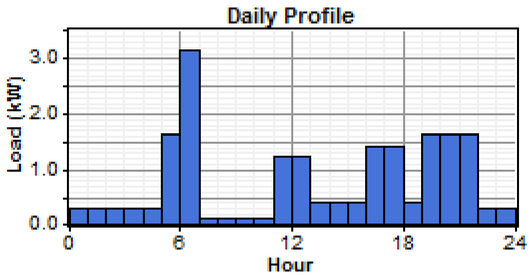

Fig. 4 Spring season load

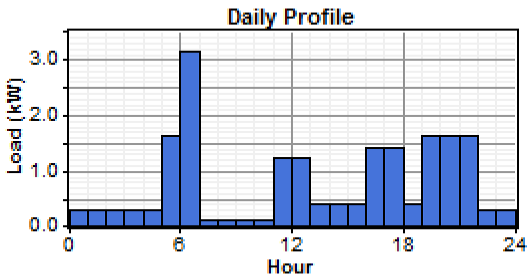

Fig. 5 Autumn season load

The solar resource of the site was obtained automatically by Homer from the NASA Surface Meteorology and Solar Energy web site with 24°17'N North latitude and 23°15'E East [14]. The annual average solar radiation for this area is 6.37kWh/m^2/d. Figure 6 shows the solar resource profile over a one-year period. The average monthly wind speed as obtained from NASA Surface Meteorology and Solar Energy web site [14] is shown in Figure 7.

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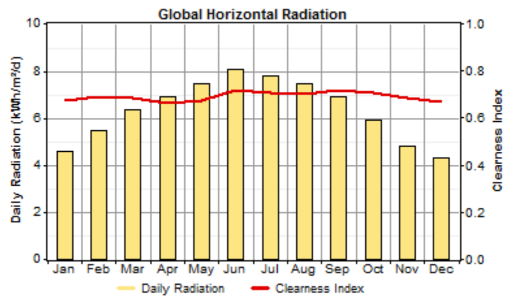

Fig 6. Solar radiation profile for Alkufrah city

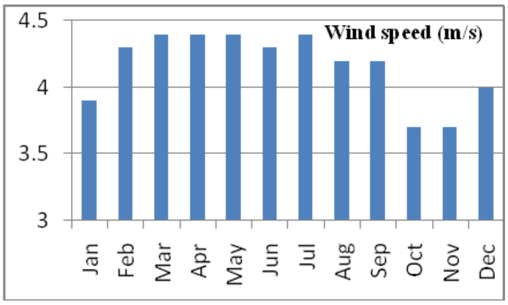

Fig. 7 Monthly wind speed

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.

2.1 Equipment Considered

The load calculated thus far is constant for each day of the month. In reality, the size and shape of the load profile will 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 19kW, as can be observed in figure 8 other information which has been input to the calculation program is summarized in Table 3. This information includes the sizes and prices of the hybrid setup components which have been obtained from the respective journals.

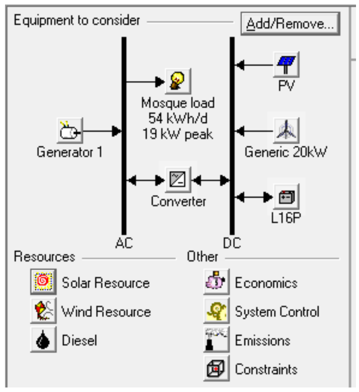

Fig. 8 HOMER diagram for the hybrid system setup

Table 3 Components of the hybrid system

Component	Size (kW)	Capital cost ($)	Replace cost ($)	O&M cost ($)	Life time	References
PV panels	1	5600	5600	0	25 years	K.Y. Lau et al .(2010) [12]
Wind turbine	20	45000	30000	900	25 years	Getachew Bekele, Bjorn Palm.(2009) [11]
Generator	1	1000	800	0.05/h	15000h	Souissi Ahmed et al.(2010) [13]
Trojan L-16 battries		275	275	3	1075 kWh	Souissi Ahmed et al.(2010) [13]
Inverter	1	700	700	0	15 years	Getachew Bekele, Bjorn Palm.(2009) [11]

2.1.1 Photovoltaic Panels, Batteries, Inverter

Photovoltaic panels were specified with capital and replacement costs of 5600$ 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.

Trojan L-16s were chosen because they are a popular and inexpensive option. HOMER considered 0 to 200 of these batteries. In a real installation a smaller number of larger batteries, such as the Trojan L-16, would be preferable. The economic analysis performed by HOMER would not be significantly affected by this distinction. 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$.

The inverter and rectifier efficiencies were assumed to be 90% and 85% respectively for all sizes Considered. HOMER simulated each system with power switched between the inverter and the generator. These devices were not allowed to operate in parallel. In this simple system, power cannot come from both the generator and the batteries at the same time. Initially cost for the converter is 700$, and the cost replacement is 700$. The operation and maintenance cost add further zero.

2.1.2 Wind Turbine

The wind turbine has a capacity of 20kW. Its initial cost is 45000$ and its replacement at 30000$. Annual operation and maintenance cost is 900$. Its hub and anemometer is located at 20 meter height. The turbine is estimated to last the project.

2.1.3 Diesel Generator

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.

3 Results And Discussion

3.1 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 4 the system of this optimal solution is PV/Gen/Battery power system and it seems to be the most feasible economically with a minimum total net present cost (NPC) of 184094$ and minimum cost of energy (COE) of 0.478 $/kWh, although the system represents a higher initial capital of 62475$ and represents renewable fraction of 31%.This optimal configuration is composed of 7 kW panel photovoltaic, 10 Generators, 33 batteries and 6 kW power converters.

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

Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 4.32 Wind Speed (m/s) 3.79 Diesel Price ($/L) 0.75

Double click on a system below for simulation results.

PV (kW)	G20	Gen (kW)	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen (hrs)
7		10	33	6	$ 62,475	6,229	$ 184,094	0.478	0.31	4,641	1,537
		9	14	7	$ 17,750	9,382	$ 200,925	0.521	0.00	7,496	2,590
1	1	9	53	7	$ 79,075	6,582	$ 207,579	0.539	0.35	4,333	1,532
	1	8	33	8	$ 67,675	7,254	$ 209,302	0.543	0.28	4,739	1,836
35			129	18	$ 244,075	2,895	$ 300,597	0.780	1.00		
32	1		121	18	$ 270,075	3,637	$ 341,084	0.885	1.00		
5	1	15		5	$ 91,500	20,224	$ 486,344	1.262	0.00	14,347	5,750
5		16		4	$ 46,800	24,318	$ 521,563	1.353	0.00	17,986	6,785
	1	16		5	$ 64,500	25,178	$ 556,068	1.443	0.00	17,899	6,789
		16			$ 16,000	31,375	$ 628,554	1.631	0.00	23,126	8,759
	10		388	18	$ 569,300	17,008	$ 901,357	2.340	1.00		

Table 5 Optimization results for average renewable resources and fuel price

Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 6.34 Wind Speed (m/s) 4.81 Diesel Price ($/L) 0.5

Double click on a system below for simulation results.

PV (kW)	G20	Gen (kW)	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen (hrs)
5		9	31	7	$ 50,425	4,971	$ 147,485	0.383	0.33	4,414	1,560
	1	8	42	10	$ 71,550	4,496	$ 159,322	0.413	0.52	3,174	1,260
1	1	7	41	9	$ 75,175	4,338	$ 159,861	0.415	0.54	3,032	1,393
		9	14	7	$ 17,750	7,449	$ 163,189	0.423	0.00	7,481	2,612
21			123	16	$ 162,625	2,831	$ 217,905	0.565	1.00		
17	1		101	17	$ 179,875	3,223	$ 242,798	0.630	1.00		
2	1	15		7	$ 76,100	14,636	$ 361,842	0.939	0.00	12,503	5,032
	1	15		6	$ 64,200	16,443	$ 385,219	0.999	0.00	14,124	5,684
4		16		4	$ 41,200	19,512	$ 422,136	1.095	0.00	17,694	6,687
	4		334	18	$ 284,450	10,542	$ 490,268	1.273	1.00		
		16			$ 16,000	25,594	$ 515,679	1.338	0.00	23,126	8,759

Table 6 Optimization results for maximum renewable resources and minimum fuel price

Sensitivity Results | Optimization Results

Sensitivity variables

Global Solar (kWh/m²/d) 8.06 Wind Speed (m/s) 6.02 Diesel Price ($/L) 0.25

Double click on a system below for simulation results.

PV (kW)	G20	Gen (kW)	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen (hrs)
4		9	24	7	$ 42,900	3,914	$ 119,311	0.310	0.29	4,701	1,685
		9	14	7	$ 17,750	5,559	$ 126,274	0.328	0.00	7,483	2,650
	1	7	24	11	$ 66,300	3,081	$ 126,446	0.328	0.62	2,579	1,224
1	1	7	19	11	$ 70,525	3,005	$ 129,197	0.335	0.64	2,460	1,184
18			107	16	$ 141,425	2,915	$ 198,328	0.515	1.00		
14	1		62	16	$ 151,650	2,459	$ 199,650	0.518	1.00		
1	1	15		9	$ 71,900	9,530	$ 257,967	0.669	0.00	10,165	4,112
	1	15		8	$ 65,600	10,381	$ 268,282	0.696	0.00	11,143	4,513
	2		283	18	$ 180,425	7,735	$ 331,444	0.860	1.00		
4		16		4	$ 41,200	14,948	$ 333,040	0.864	0.00	17,523	6,629
		16			$ 16,000	19,812	$ 402,804	1.045	0.00	23,126	8,759

For the case when the renewable resources and the fuel prices are at average values as in Table 5 The optimal solution of this case is the first row which is combination of 5 kW panel photovoltaic, 9

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Generators, 31 batteries and 7 kW power converters, and the system is PV/Gen/Battery power system with a minimum total net present cost (NPC) of 147485$ and minimum cost of energy (COE) of 0.383 $/kWh, although the system represents a higher initial capital of 50425$ and represents renewable fraction of 33%. When the renewable resources are at maximum and the fuel price is minimum the most feasible economically system of this case is shown in Table 6 which is PV/Gen/Battery power system also with combination of 4 kW panel photovoltaic, 9 Generators, 24 batteries and 7 kW power converters. The total net present cost (NPC) of this system is 119311$ and minimum cost of energy (COE) of 0.310 $/kWh, although the system represents a higher initial capital of 50425$ and represents renewable fraction of 29%.

3.2 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 Figures 9-11 respectively.

In Figure 9 when the diesel price is minimum the PV/Gen/battery is always the winner but when the diesel price is average as in Figure 10, the Wind/Gen/Battery combination takes over when the wind speed exceed 4.76 m/s at 4.34 kWh/m^2/d, the wind energy share decrease sharply as the solar radiation increase until 6.32 kWh/m^2/d, at that point the Wind/Gen/Battery combination in becomes the best only when the wind speed is over 5.52 m/s, after that the decrease of the importance of this combination becomes less sharp. Increasing the Fuel price to \$0.75 as in figure11 does not impose a noticeable change; it gives slightly less sharpness in the decrease of the importance of the wind energy as solar radiation increase.

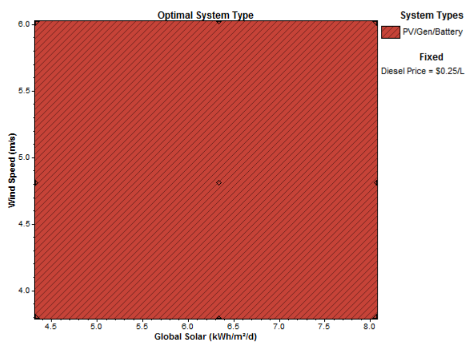

Fig. 9 Ssensitivity results with diesel price of \$ 0.25

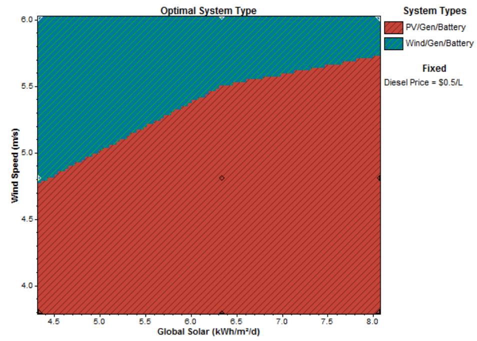

Fig. 10 Ssensitivity results with diesel price of \$ 0.5

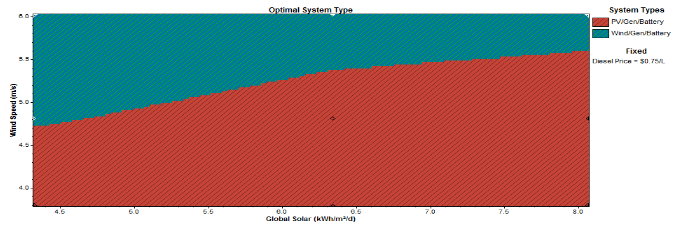

Fig. 11 Ssensitivity results with diesel price of \$0.75

4 Conclusion

The simulation results indicate that the electricity supply for the mosque could be generated most economically and ecologically by installing PV/Gen/Battery power system. Because the load profile in summer and winter are much higher than spring and autumn; the excess electricity from the hybrid renewable power system in spring and autumn can be used in other applications or it can be sold in the future to the utility grid to reduce the cost of energy.

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