

Design and Evaluation of hybrid stand alone electric system for Masirah Island

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Abstract

With the ever-increasing demand for electric energy, alternative sources are being considered and exploited. The various researches, technical and engineering studies have shown that hybrid energy systems using renewable sources are very promising. As these will witness more interest due to development technologies and increase in hydrocarbons prices. This paper presents a design and evaluation approach of hybrid stand alone electric system for Masirah Island, in Oman. This is based mainly on coupling available diesel generators to PV station to cover the expected load increase at the Island. Solar illumination data has been averaged for a certain number of years with an

average of 6.22 kWh/m²/day. The simulations of the designed system have been carried out with the help of Homer software for many scenarios. The simulations with ten diesel generators, a 2 MW PV station and back up batteries gives a low penetration ratio percentage required to make the generating system stable. The cost of the designed hybrid system was done at an actual diesel cost of 0.468 US\$/liter, and 3 US\$ per watt for the PV system. Batteries were considered for the current design to maintain more stability even though the required load demand coincides with the peak solar radiation.

Keywords: Hybrid system; PV station, Diesel generator, Renewable Energy, Masirah Island.

1. Introduction

The utilization of renewable energy resources will be of no doubt increasing in the coming years as the world population is growing, the hydrocarbon prices increasing, exploitation of more remote areas in agricultural production and other needs appearing. Global warming effect is also pressing to diversify the energy sources which will certainly drive naturally towards more usage of renewable energies [1]. Solar energy from photovoltaics is a clean energy source and the use of this technology has seen a tremendous increase in the last few years and will continue its trend in the future. This fact is depicted in **Figure 1** showing the development of PV world market in MW for two decades, from 1997 until 2007. One can note the tremendous increase in the last two years from 2005 to 2007. This shows that the use of PV surmounted the most optimistic expectations and is still continuing increasing. The production was expected to reach 3.5 - 3.8 GW in 2007, however, the actual figures are almost two times these expectations [1-8]. The solar PV industry is also witnessing a boom in silicon production facilities around the world, responding to silicon feedstock shortages of the recent past years. By the end of 2007, more than 70 silicon-manufacturing facilities were being con-

structed or planned to be built. However, the main current drawback is its relatively high cost compared to other sources. Nevertheless, the costs are dropping continuously and a remarkable market development is planned to take place. The photovoltaic world market in 2002 was more than 500 MW peak per year corresponding to a value of roughly 1 billion dollars [9-10]. The market growth in the last decade was from less than 25% per year and has risen recently to 40% and then to more than 80% (refer to **Figure 1**).

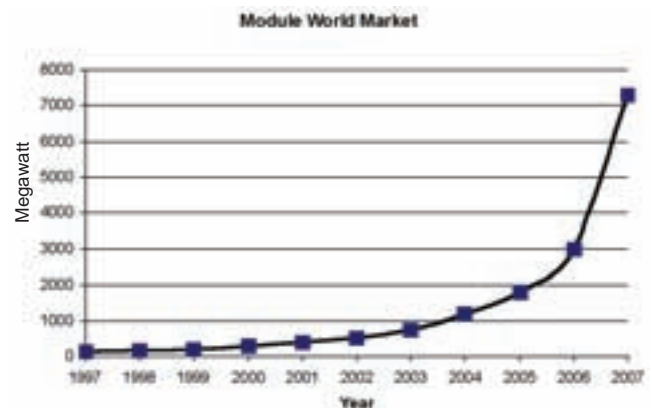


Figure 1. Development of PV world market during two decades, 1997 to 2007, in MWatt [9-10].

The two major markets of the PV energy are the grid-connected and the standalone systems. A recent study of possible future energy scenarios up to the year 2060 published by Shell company predicts a multi-Giga-watt energy production by renewable energies, including photovoltaics. On the other hand, the strong competition leads to very low profit margins of most participants of this market, which is actually about 3 US\$ per watt including the installation construction.

The hybrid renewable energy systems are systems composed of more than a type of power generator. They usually combine diesel generators, with one or certain number of renewable energy sources such as wind, PV, or their combination. These have become attractive alternative sources for power production because they allow exploiting the strength of various renewable energy sources combined with conventional generators [2-6]. A well studied combination of diesel and PV system will not require a huge storage particularly for the case of Masirah Island presented here. PV system will support the load expansion and requirements for about 9 hours and the diesel generators will provide the necessary back up in absence of incident solar radiation.

The model of the PV generator in Homer is presented as an electrical generator that provides a power proportional to the global incident solar radiation with no effect of temperature being considered. The output power is expressed by equation (1) below:

$$P_{out} = \eta_{PV} C_{PV} \frac{I_T}{I_S} \quad (1)$$

Where P_{out} is the delivered output power by the PV arrays, η_{PV} and C_{PV} (kW) are respectively the PV generator derating factor and its rated capacity. I_T is the total solar radiation in (kW/m²) and I_S is the standard amount of radiation used to rate capacities of the PV arrays, which is 1kW/m². The standard temperature considered in the computations model is 25 degree Celsius.

As the current power system design needs to fit the Island of Masirah, a solar radiation profile for Masirah together with two other main locations in Oman are depicted in Figure 2 [8]. These are for the areas of Muscat and Marmul which are the capital and a field for oil production. Note the presence of two peaks of solar radiations that occur respectively in May and September. It is also worth noting that temperature is also a factor, which will affect the operation of PV solar arrays as well as the diesel generators.

A seasonal temperature variation profile in Oman during the period 1974-1990 for 12 months (Jan. 1- Dec. 12) is shown in Figure 3 [8]. The four curves shown indicate, Mean maximum temperature, Mean temperature, Mean minimum temperature and Mean daily sunshine in the area of Muscat.

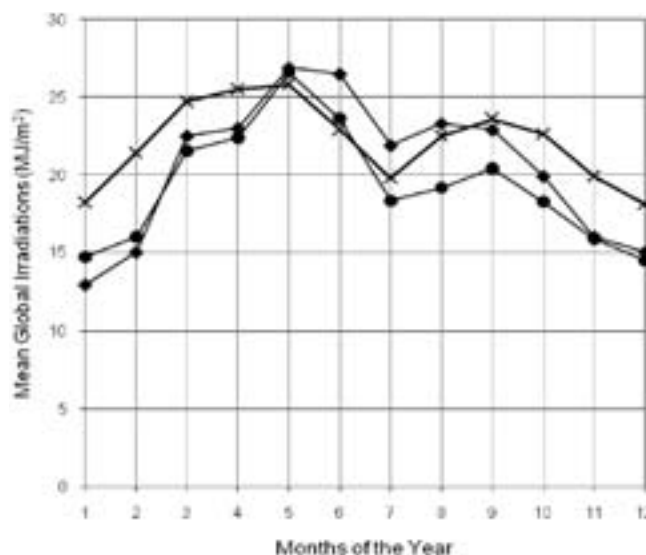


Figure 2. Radiation data graph for three different locations in Oman. These are Masirah Island (●), Muscat (♦), and Marmul (x)

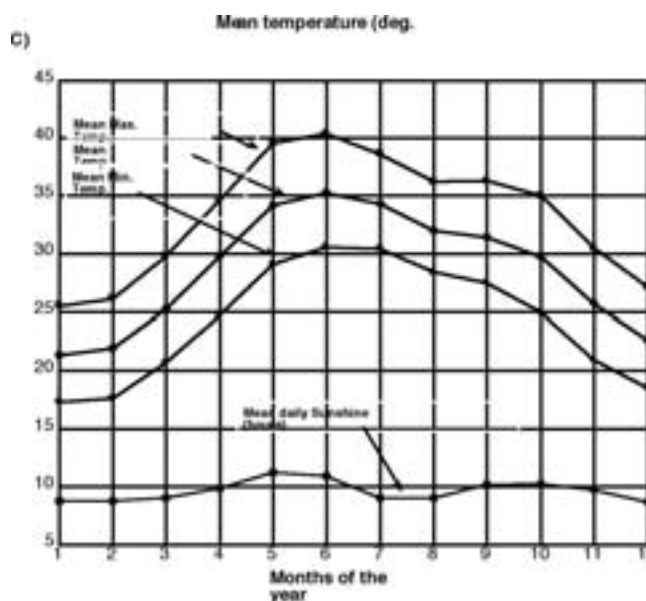


Figure 3. Seasonal temperature variations in Oman around the Muscat area during the period 1974-1990 for 12 months (Jan. 1- Dec. 12). The four curves shown indicate, Mean maximum temperature (°C), Mean temperature (°C), Mean minimum temperature (°C) and Mean daily sunshine.

Masirah is the Oman's largest island located some 15 km from the coast of Arabian Sea and has a length of about 65 km. It is a Desert Island and attracted by many tourists, scientists and investigators. It is situated at 20° 40' 32" N 58° 53' 26" E.

In this paper, a design and study evaluation of a hybrid stand alone electric system for this Island will be demonstrated. It is mainly composed of ten existing diesel generators, a PV plant and a set of batteries. The system is sized and studied to provide the Island with electricity needs [11].

2. Environmental parameters and design criteria

In many isolated locations of Oman, like the Masirah Island, utility grid extension is either very expensive or impractical to implement and maintain. It is thus important to look for alternative combinations of renewable energy sources like solar PV, wind, diesel generators to be supported by rechargeable batteries.

A rapid expansion in the use of RE sources as replacements or complements of the oil based energy are witnessed. Solar energy which is a carbon free emitter is expected to play an important role in the future [9-10, 12-13]. This is valid for solar thermal generators as well as PV generators.

With reference to *Figures 2 and 3*, Oman has got a potential of the two energy sources above. Moreover, the use of solar energy reduces combustion of fossil fuels and the consequent emission of carbon dioxide, refer to e.g. [14]. Although, the amount of available solar energy is huge, the technologies are not able to drive the needed amounts as the transforming systems are still expensive mainly the PV option were more applications are found in remote areas or special applications in telecommunications, military, and mobile systems [15].

The current load profile at Masirah Island as provided by the Rural Areas Electricity Company, Oman, is depicted in *Figure 4* below [11]. The average expected load profile per month is shown in *Figure 5*. Since the performance of the hybrid energy system to be designed is dependent on the environmental conditions mainly temperature, it is not recommended to run the diesel generators overloaded.

The details of the operating regimes for the ten (10) generators, G_1 to G_{10} , are indicated on *Table 1*. Note that the design and performance evaluations of the suggested system has been based on site capacities and not on rated powers. The yearly site operating temperature profile of the engines is shown in *Figure 6*.

TABLE 1. Characteristics of the Diesel engines used to feed Masirah Island [11]

Engine No.	Engine Ref.	Engine Rated Capacity(KW)	Engine Site Capacity (KW)
G1	MBS	265	212
G2	MBS	265	212
G3	MBS	265	212
G4	MBS	265	212
G5	MBS	265	212
G6	KHD	3136	2509
G7	KHD	3136	2509
G8	Caterpillar	1000	800
G9	Caterpillar	1000	800
G10	Cummins	1000	800

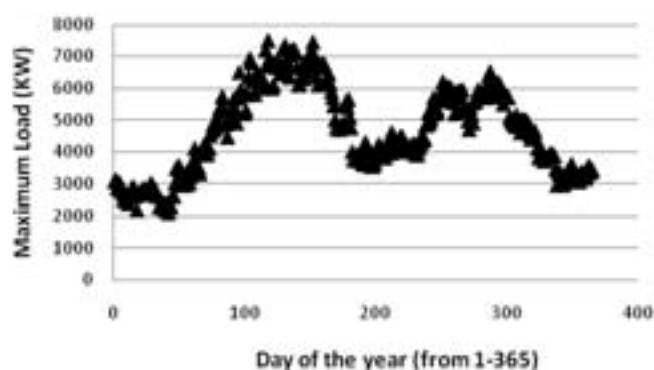


Figure 4. Maximum Load profile for Masirah Island for the year 2008.

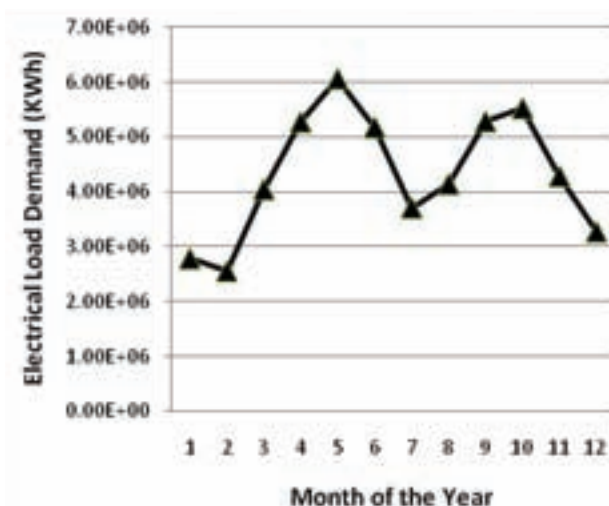


Figure 5. Average energy generated in Masirah in kWh for every month, 1-12.

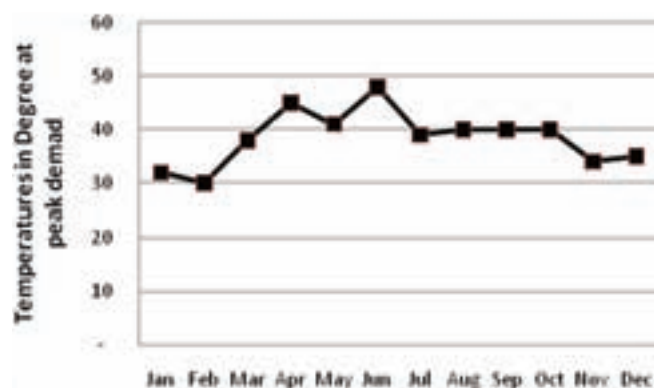


Figure 6. Temperatures at peak Power demands for masirah in Deg Celcius per month during the year 2008.

Based on the expected load profile shown on *Figure 5*, a power system based on hybrid Diesel-PV technology has been prepared. The design has been directed towards the use of PV as a complementary sources of energy, as it is a clean technology, the place is virgin and needs to be maintained quite with no wind generators even though wind speeds can surpass the 6m/s. The Homer software, developed by NREL,

has been used to perform the overall system operation analysis and cost estimation [16].

Homer is a computer model that simplifies the task of evaluating design options for both off-grid and grid-connected power systems. Analysis with Homer requires information on resources, economic constraints, and control methods. It also needs inputs on load data, renewable resources data, component types, their numbers, costs and efficiency. It has capabilities to model both conventional and renewable energy technologies and able to perform automatic sensitivity analysis to account for the variations of the system design to key parameters, such resources availability or component costs. A block diagram of the designed system is shown in *Figure 7*.

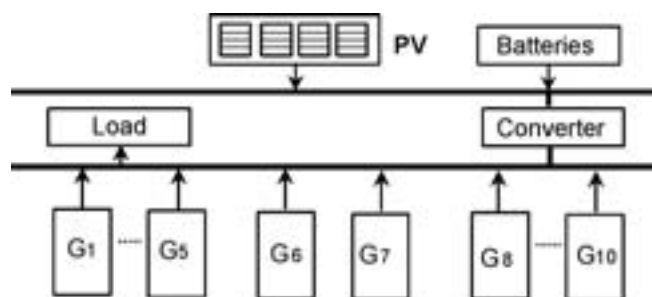


Figure 7. System Architecture as it is currently connected and evaluated. G₁ to G₅ are diesel generators rated 265kW, G₆ and G₇ are rated 3136kW and G₈ to G₁₀ are rated 1000kW. The PV generator is rated 2000kW.

It is well known that the use of diesel-PV combined system reduces the battery storage cost as the two sources can complement each other [14]. In particular, when the diesel generators are operating at high efficiencies. This will reduce the overall cost of the Diesel-PV system.

Several simulations and a large number of sensitivities have been considered to tune the designed system to reach the optimum configuration with the best overall cost. The sensitivities are mainly put on the parameters of the main load, the PV arrays, system control and constraints.

A number of 18 (eighteen) simulations have been generated where 864 sensitivities were generated for each case. These mainly concern the following parameters of the system. The main load storage capabilities was kept varying between 2000-5000 kWh, the PV derating factor was changing between 70 to 90%. The ground reflectance of the solar arrays were changing between 10 and 20 % as the seasonal dust deposition might have a significant effect. The maximum annual capacity shortage was set to vary between 1 to 10% and the minimum renewable fraction was set to vary between 0.5 to 10%. As it might be subject to some variations in the future, the cost of the diesel fuel has been made changing from 0.368 \$/ liter to 0.568 \$/liter. In order to assure convergence of the computations, the system control inputs were set to vary from simulation intervals of 60 minutes to 350 minutes.

The performance and feasibility analysis of the system of *Figure 7*, has been done with the ten generators operated at their site limits in conjunction with a PV solar station having variable capacity. The one adopted of 2 MW has an energy production forecast as indicated in *Figure 8*. For an average operation period of 20 years, the PV plant is expected to deliver a total energy production of about 62,000 MWh. The total energy production in kWh/yr for each diesel generator and PV plant of the hybrid system in tabulated format is shown in *Table 2*. This is for a main load storage of 5000 kWh and for diesel fuel costs of 0.386\$/liter, 0.486\$/liter and 0.586\$/liter.

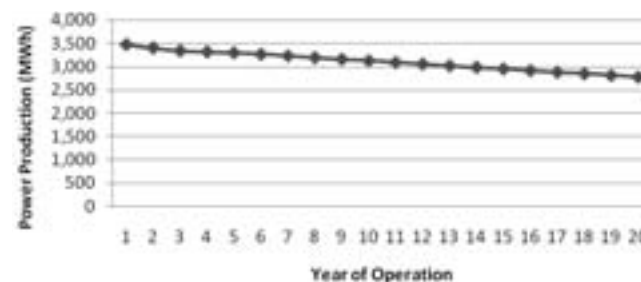


Figure 8. Energy production forecast of the 2MW PV plant for a period of 20 years.

TABLE 2. Total energy production in kWh/yr for each generator of the hybrid system in tabulated format for fuel costs of 0.386\$/liter, 0.486\$/liter and 0.586\$/liter. The main load storage is 5000 kWh.

Factor	PV array	G1-265	G2- 265	G3-265	G4-265	G5-265	G6-3136	G7-3136	G8-1000	G9-1000	G10-1000
Production (KWh/y)	8,841,532	1,630,704	824,256	206,064	10,176	2,544	21,692,832	9,996,065	2,524,800	1,036,800	5,458,264
Fuel: 0.368 \$/l											
Production (KWh/y)	8,841,532	1,630,704	824,256	206,064	10,176	2,544	21,692,832	9,996,507	2,524,800	1,036,800	5,457,894
Fuel: 0.348 \$/l											
Production (KWh/y)	8,841,532	1,686,672	1,020,144	419,760	203,520	22,896	21,688,440	9,934,645	2,524,800	1,056,000	4,822,915
Fuel: 0.358 \$/l											

The overall performance of the system, gives a total excess electricity of 166,227 kWh/year which represents a percentage of 0.32%, an unmet electric load percentage of less than 0.005% and a Capacity shortage of less than 0.005%. The yearly total electric production for the designed system depicted in a graph format for a main load storage of 5000 kWh for a diesel fuel cost of 0.468\$/liter is shown in *Figure 9*. The optimized operation system performance has been obtained for maximum use of solar energy in peak radiation periods, optimum operating regimes of all diesel generators to minimize fuel cost and maximize efficiency and the optimum cost for minimum polluting gases generated.

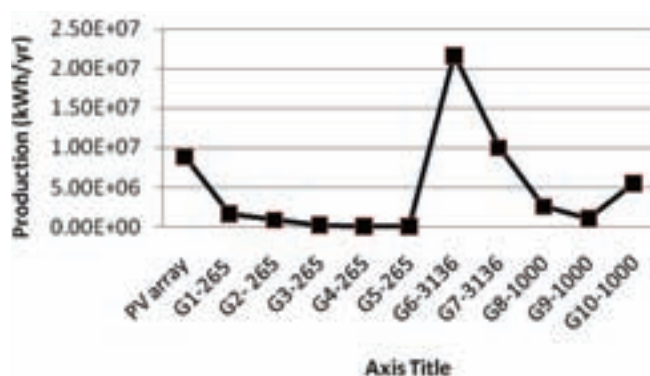


Figure 9. Total energy production in kWh/yr for each generator of the hybrid system for a main load storage of 5000 kWh. The fuel cost is 0.486\$/L.

A summary of obtained performance with regard to excess electricity, unmet electric load and capacity shortage at different load storage capacities of 5000 kWh, 4000 kWh and 2000 kWh is reported in *Table 3* below.

TABLE 3. Summary of designed system performance at different load storage capacities. These are 6000, 4000 and 2000 KWh.

Main load storage of 5000 kWh

Quantity	kWh/y	Percentage
Excess electricity	570,661	1.09
Unmet electric load	0.00	0.00
Capacity shortage	0.00	0.00

Main load storage of 4000 kWh

Quantity	kWh/y	Percentage
Excess electricity	154,431	0.30
Unmet electric load	0.00	0.00
Capacity shortage	0.00	0.00

Main load storage of 2000 kWh

Quantity	kWh/y	Percentage
Excess electricity	0.354	0.00
Unmet electric load	0.00	0.00
Capacity shortage	0.00	0.00

Conclusions

The renewable energy industries and applications will certainly witness more developments in the near future as the other energy sources are becoming either expensive or being depleted. This paper presents a design and evaluation approach of hybrid stand-alone diesel-PV system for Masirah Island. It is based mainly on coupling available ten diesel generators to a 2 MW PV station with back up batteries to cover the expected load increase of the Island. With an average solar illumination of 6.22 kWh/m²/day, the inclusion of PV generators seems a very attractive solution as it is a clean technology and fits touristic zone like Masirah Island. The simulations of the designed system have been carried out with the help of Homer software made available by NREL. The cost of the designed hybrid system was done at different diesel fuel costs and a current diesel cost of 0.468 US\$/liter, and 3 US\$ per watt for the PV system. The system suggested has a good coherence between the solar radiation profile and the peak load demands particularly in May and September. The operating regimes of the diesel generators are set to minimize the fuel cost and maximize operation efficiency, which gives an optimum cost and reduced amount of polluting gases generated.

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