Review and design of a standalone PV system performance

Ali H. Al-Waeli, *Member, IEEE*, Hussein A Kazem, *Senior Member, IEEE*, and Miqdam T Chaichan

***Abstract*—Global interest in solar power has reached new highest with continues efforts by governments and organizations to establish a stance against fossil fuel dependence and the high percentage of carbon dioxide emitted by the industrialized world. Employing renewable energy technologies like solar power seems to be a good viable option, especially for third world countries which happens to receive huge amounts of solar radiation around the year. This paper presents study and design a common PV system configuration and how to optimize the results in order to build the best cost efficient technology. The numerical analysis through two main software HOMER and REPS.OM is carried out. HOMER optimal configuration showed an energy cost of 0.315 USD/kWh while, REPS.OM's cost of energy was around 0.151 USD/kWh. A clear difference between these two tools might indicates that specialized MATLAB-coded software is more accurate than global tools which are designed to provide close results. Either tools show great promise for the 'photovoltaic' technology and its implementation in the Sultanate of Oman.**

***Index Terms*—Solar power; photovoltaic; carbon emissions; HOMER; REPS.OM; numerical design**

I. Introduction

THE state of renewable energy evolution is at all-time high, many organizations and countries are advocating for the utilization of renewable energy across the world in order to decrease carbon emissions and dependency on fossil fuel. Continues fluctuation in fossil fuel industry is a clear indication that fossil fuel cannot be the only source, as well as the proven research of its effect the global warming. Countries like the Sultanate of Oman are highly depended on fossil fuel, where in 2012 the sultanate was the 24th biggest oil-exporting country in the world with 64% of its revenue coming from oil. Natural gas is the largest vital sector in Oman, with around 29 billion cubic meters of gas per year sold [1]. Developing a renewable energy market in Oman is important and crucial to bring the country up to date and allow citizens to utilize the multiple resources of energy. Replacement of oil and gas may seem like a hard goal to achieve however; first steps must be taken towards such goal. The solar cell is one of the most popular technologies around the world due to the advantages it possesses, where it is easy to relocate due to its light weight, dependent on the sun which happens to exist everywhere, noise free because no mechanical or combustion process needs to happen, and can be bought easily in the markets by users especially with its decreasing prices.

Oman area is 309,500 km^2 and located in the south-eastern part of the Arabian Peninsula between latitudes 16° 40' and 26° 20' north and between longitudes 51° 50' and 59° 40' east. Solar radiation across Oman and the Arabian Peninsula shows a massive potential for the solar cells technology or as it's called photovoltaic. The concept of photovoltaic technology revolves around the conversion of light into electricity with the use a semiconductor device. Various systems and configurations for photovoltaics (PV's) exist and it depends on the use of the PV as well as the load it is intended to supply [2, 3].

II. Literature Survey

A lot of research about the use of photovoltaics for home appliances and other have been done which shows the important of targeting such sector in the solar energy industry. Kazem. H (2013) [4] present an optimal sizing design method for a standalone PV system in remote areas in Sohar - Oman. The proposed model in term of low cost and good performance look to find PV tilt angle and size of the system. Hourly measured meteorological data and load demand has been simulated by MATLAB where Numerical methods used in optimization. The optimization used to find the PV tilt angle and size, also the storage battery capacity was implemented, the results show that must be adjusted twice a year. The average daily load demand is 6.13 kWh daily, with a peak power of 520 W and the cost of the energy of 0.196 USD/kWh [4].

Souissi et al. (2010) [5] planned an optimization solution of a renewable energy hybrid system through HOMER software for Tunisian rural areas. The Hybrid systems considers combination of different energy sources like PV/battery, wind/battery, wind/PV /diesel/battery, wind/PV/battery, etc. Specific climatic data Hawaria area in Tunisia was used as input. To satisfy load demand renewable energy may have interruption and so the diesel generator combined with a wind-PV-battery hybrid system where it is used as auxiliary source to ensure a more reliable supply without interruption. The optimal configuration for the reliable load supply hybrid system (wind/PV/diesel/battery) that considered the

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meteorological data changes is deduced from two selected optimal configurations: (diesel/battery) and (wind/PV/battery). The optimal configuration for the wind/PV/battery system is composed of 8 kW PV panel, 2 wind turbines, 118 batteries & 12 kW power converters. The total Net Present Cost (NPC) is USD 189.559 and the cost of energy produced is USD 0.540 per kWh. The optimal configuration for the diesel / battery is composed of 5 kW diesel generator, 18 batteries and 2 kW power converters. It's total NPC is USD134.747, its cost energy produced is USD 0.382 per kWh and the diesel 11.269 L. For the wind/PV/diesel generator/battery with load of 85 kWh/d the optimal configuration is consists of 8 kW panel PV, 2 wind turbines, 118 batteries, 5 kW diesel generators & 12 kW power converters. After having determined the optimal configuration of the hybrid wind-PV-battery system in terms of reliability and economy, authors showed the effect of the climatic change on the reliable supply of the load and proved that the diesel generator, as buck-up source, with the hybrid wind/PV/battery system combination is a great solution to a reliable supply without interruption of the load under the climatic data change [5].

Zeinab A. M et al. (2012) [6] discussed a sustainable renewable energy efficient system used for domestic demand in Khartoum, Sudan. The proposed technique relied on the collection of wind speed, basic solar radiation and other required input data, then HOMER software used to design a hybrid optimization simulation model. The proposed model had a load of 54 kWh per day, and 5.3 kW as its peak. The cost of the PV module including installation has been considered as 220 SP/W for Sudan. The optimum system found to be wind/PV combination for 50 homes instead of single home system moreover, based on the conducted analysis the project's life time has been measured to be 25 years, while the annual real interest rate is chosen at 4%. The load consumed by the users is of low maintenance and operation cost, the author claimed that the system has been planned for single and multiple home users like 10 to 25. For optimization software HOMER has been used in designs and evaluating of both grid-connected and off-grid power systems for a range of applications [6].

Ajao K.R. et al. (2011) [7] investigated the hybrid/solar power generation cost benefit relative to use in Nigeria. The wind/solar hybrid system cost benefit analysis has been done through HOMER software and compared with utility supply. The national grid power is the least luxurious option but, it may not be available rural area. Hence renewable energy sources could be the best option for rural area.

The author claimed that best system used has 0.05–0.4 kW PV array with 0.4 kW DC FD series wind turbine, (0.1 – 1.5 kW) converter, and (200 Ah / 12 V, bank size: 1-8 batteries, vision 6 FM200D) battery. HOMER's result gave a total NPC of USD 4251 and a Cost of Energy (CoE) of USD1.74 per kWh [7].

There are many studies in literature investigated the design of PV systems [8-16]. From the literature review a few points are taken into consideration in designing a PV system:

1. Employing stand-alone PV systems for rural areas is an effective method and backing it up with diesel engine (hybrid) will improve the reliability of the system.
2. Design of the PV system based on the exact location of installation is a crucial element for more accuracy which provides better results.
3. Use of numerical analysis to find the optimal configuration is more accurate than other types of analysis, especially with tools such as HOMER software.
4. Lifetime of the projects are generally around 25 years (as it is the lifetime of solar cells).

III. Numerical Design of Standalone PV System

The general configuration of a stand-alone PV system is to use PV panels, inverter, charge controller and batteries to supply the load. The output of the PV cell is a Direct Current (DC) however, most home appliances are powered with Alternating Current (AC) therefore, and the inverter is a crucial component for the system. The charge controller will regulate the voltage and protect both the batteries and the PV panels. Batteries will store the DC electricity during day-time then will release it to inverter (to be converted to AC) during night-time to power the load intended.

For the numerical design of the PV system two tools have been used in this paper which are HOMER and REPS.OM software.

A. HOMER Design

Description of the proposed system in this study using HOMER software, the assessment of solar energy cost per kWh at Sohar-Oman. Data weather station acquisition is used for acquiring data of the ambient conditions to measure: solar radiation hourly, ambient temperature, global irradiance, wind speed and direction and relative humidity. It recorded data that have been used to assess solar energy potential in Sohar and it is found that the average global horizontal solar resource is about 4.3kWh/m^2/day . Different design options are compared in HOMER in term of economic and technical merits. It is also supports in quantifying and understanding the effects of changes or uncertainty in the inputs. Figure 1 shows the proposed system schematic diagram.

The system configuration of Fig. 1 consists of a PV, converter, battery bank and loading system from HOMER software that have been used.

The PV module used in this paper is a 280 Wp PV installed at Sohar zone for search work purposes. Table 1 below shows the specifications of the modeled PV system.

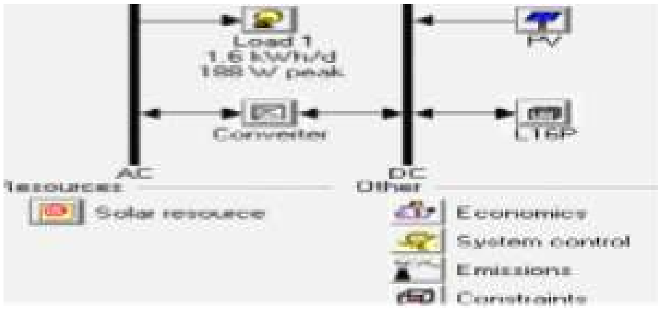

Fig. 1. HOMER schematic diagram for the PV system.

Table I shows the specification of the solar cell, where in this project each with 140Wp (2 modules) means a rated power of 280 W/PV array with two batteries in series for 50 Ah each, that selected to install on top of the engineering building in Sohar University. The system contains PV array, an inverter, batteries, solar charge controller and special cables in order to efficiently connect the source to the load.

TABLE I
MODELED STANDALONE (SA) 1680 W PV SYSTEM SPECIFICATION

PV module	
"PV module rated power"	140 Wp (2 module)
"Maximum voltage"	17.7
"Maximum current"	7.91
"OC Voltage"	22.1
"SC current"	8.68
"Efficiency"	13.9%
"Temperature coefficient of Voc"	-0.36 %/k
"Temperature coefficient of Isc"	0.06 %/k

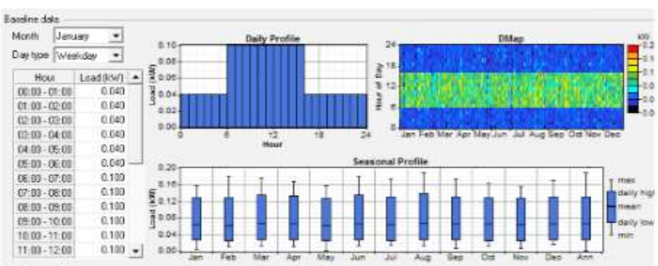

Fig. 2. Load input in HOMER software.

TABLE II
ECONOMIC OPTIMIZED OF PV SYSTEM COMPONENTS

"component"	"Capital" (USD)	"Lifetime" (Years)	"Replacement" (USD)	"O&M" (USD)	"Fuel" (USD)
PV	**1,596**	**25**	**0**	**767**	**0**
Inverter	**125**	**15**	**38**	**0**	**0**
Battery	**400**	**6**	**1,306**	**1,534**	**0**

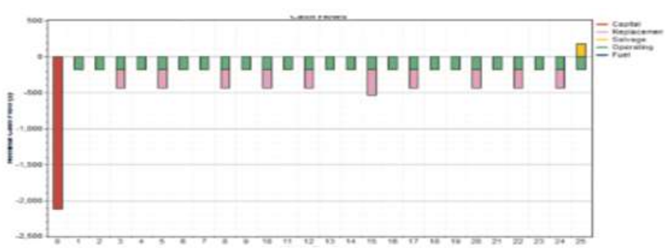
Fig. 3. Cash Flow Diagram.

A.1 HOMER software Data inputs

1. PV Array Data:

The capital and replacement costs of the PV array are $532 and USD 420, respectively. The considered maintenance costs for the panels were around 20 USD/yr which is low. A derating factor of 90 % and 25 years' lifetime was also considered.

2. Battery Data input

The chosen battery is the Vision 6FM55D. It has a nominal voltage of 12 Volts & nominal capacity of 55 Ah (0.66kWh). HOMER simulation showed the total number of batteries to be around 4.

3. Inverter Data

The efficiency of the inverter was assumed to be 94.1 % for all the considered size. The size considered is 0.300 kW.

4. Load Data

A typical lighting load was considered as shown in Figure 2. The consumption includes LED points.

A.2 HOMER software results

The PV array rate capacity is 0.420 kW and it produces 712 kWh/yr. Also, it is meaning output is 1.95kWh/d and capacity factor is 19.4 %. As for battery, it is used in almost 25 % of year time and the annual throughput is 259 kWh per year. the energy demand of the propose system is 506 kWh/yr. the initial cost, NPC of the system, and energy cost are USD 2121, USD 5.724 and USD 0.315/kWh, respectively.

As the expected of lifetime of the component of this system in input into the HOMER software for PV, Battery and Inverter: 25, 5 and 15 years respectively. The acquisition cost shown in Table II. Also, Figs. 3 and 4 shows cash flow and cash flow summary, respectively.

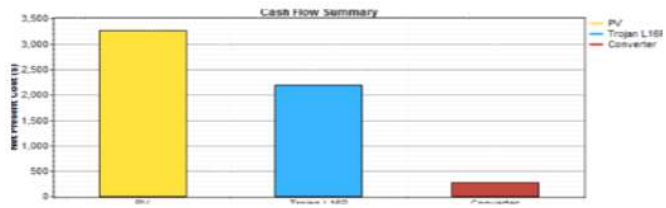

Fig. 4. Cash Flow Summaries Diagram.

B. REPS.OM Design

In REPS.OM software, it has the abilities to optimize the PV module/array tilt angle, optimizing the size of inverter & calculating the optimal capacities of PV array and battery. These methods have advantage of being more accurate in comparison with intuitive methods. Figures 5 – 8 shows REPS.OM results.

Figure 5 shows some optimum results from REPS.OM which is unavailable in HOMER, such as the tilt angle which has been found for different months through the year also, capacity factor for the array and the battery.

Figure 6 show different results from HOMER (all comparisons shown in table 3) where the Cost of Energy is about 0.1518 USD/kWh as appose to HOMER's 0.315 USD/kWh.

Figure 7 indicates system analysis to provide a clearer description of the system in terms of multiple factors and

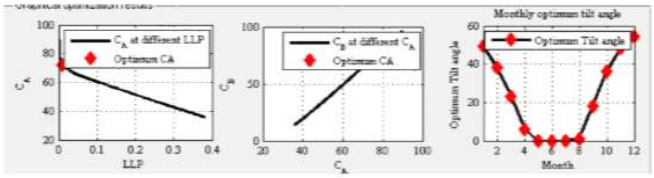

Fig. 5. Graphical optimization results.

Fig. 6. Numerical optimization results.

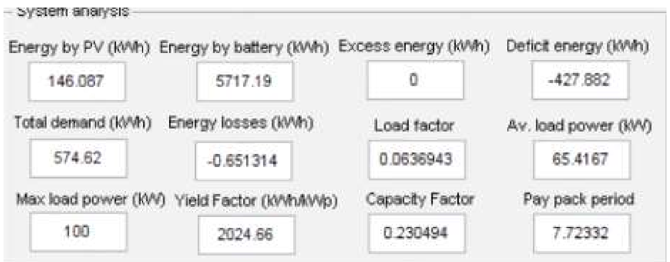

Fig. 7. System analysis.

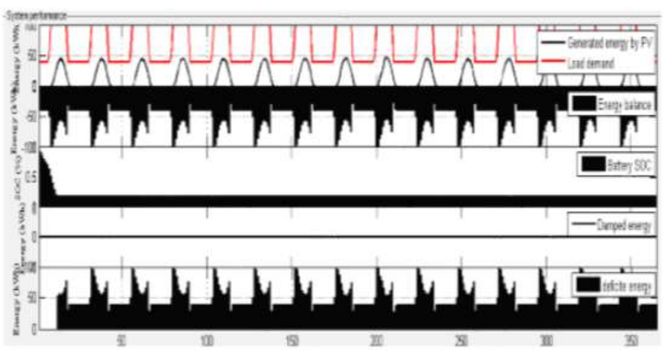

Fig. 8. System performance.

TABLE III
COMPRESSION OF TECHNICAL ANALYSIS IN REPS.OM & HOMER

	Numerical Methods	
	REPS.OM Software	HOMER Software
PV size	72.1 W	280 W
Battery size	67.84 Ah	80 Ah
Inverter size	100 W	300 W
Tilt angle	27o	24o
System Capacity factor	23.05%	19.40%
Energy losses	-0.651314 kWh	0.0876 kWh
Total production and demands	574.62 kWh	712 kWh
Excess Energy	0 %	17.8 %

energy readings which -along with the information provided in figure 8- helps to decide whether system is satisfying the load as needed or if system is not technically efficient. Table III shows a clear comparison between REPS.OM and HOMER software's results.

Further comparison of table III shows that for the battery and inverter size, where REPS.M gave less size which means

TABLE IV
COMPRESSION OF ECONOMIC ANALYSIS FOR REPS.OM & HOMER SOFTWARE

	Numerical Methods	
	REPS.OM software	**HOMER software**
Capital cost	443.798 USD	2121USD
CoE	0.151 USD/kWh	0.315 USD/kWh

less expansive. Capacity factor for the system found to be 19.4% in HOMER and 23.0494% in REPS.OM. Furthermore, energy losses in HOMER are at 0.0876 kWh while they are at -0.651314 kWh in REPS.OM. Table 4 show comparison for the economic aspects in both tools.

Finally, Table IV indicates that the CoE for HOMER's system design is twice that of REPS.OM when supplying the same load.

IV. CONCLUSION

In conclusion, Photovoltaic technology have shown great potential and especially around the middle-east where high solar radiation exists. This paper not only provides reason to why solar power need to be implemented in the Sultanate of Oman, but it also shows two different designs with two system configurations. Even though HOMER software is more popular than REPS.OM, the latter have shown great results when building a system in Oman. Where REPS.OM uses a more accurate tilt angle of 27° as appose to HOMER's 24° which is a default setting choosing based on latitude. The technical analysis of both tools shows great promise and the economic shows REPS.OM to be more cost efficient. REPS.OM found the optimal PV system for this specific load to be 0.151 USD/kWh which is about one half of its counterpart (HOMER's) that shows a CoE of 0.315 USD/kWh. Solar power is a growing field and Photovoltaics in particular needs more research and improvement to be utilized especially for home appliances where small incremental steps can make the difference in energy consumption.

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