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Original Research Article

Techno-economical assessment of grid connected photovoltaic power systems productivity in Sohar, Oman

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ABSTRACT

In this research a techno-economical methodology is presented to evaluate the productivity of a grid connected photovoltaic (PV) system in a specific site in Oman called Sohar. The methodology is based on three factors namely capacity factor, yield factor and cost of energy. The analysis is done by MATLAB software using hourly meteorological data and a model for grid connected PV system. By analysing the obtained meteorological data, it is found that the average daily solar energy in Sohar zone is 6.182 kWh/m^2 day. The assessment results show that the PV technology investment is very promising in this site whereas the annual yield factor of the system is 1696.6 kWh/kWp. Meanwhile, the capacity factor of the proposed system is 19.46%. As for the cost of the energy generated by the proposed system, it is 0.158 USD/kWh. This research contains worthwhile technical information for those who are interested in PV technology investment in Oman.

Introduction

Based on the fact that PV systems are clean, environment friendly and secure energy sources, PV system installation has played an important role worldwide. Grid connected PV systems can be divided into three parts; building integrated PV systems (BiPV) and distribution generation PV (DGPV) systems and centralized PV plants [1]. BiPV systems usually supply a specific load and inject the excess energy into the grid. On the other hand the DGPV systems inject the whole produced energy into the grid without feeding any local load. The grid connected systems can consist of a PV array only as an energy source, or another energy source can be incorporated with the PV array such as wind turbine, diesel generator or a storage unit. Finally, the third type of grid connected PV systems is centralized large PV systems connected to the utility transmission system, owned by a local utility, or third party [1].

PV systems' size and performance strongly depend on the meteorological data. In other words; PV system productivity is a location dependant variable where it varies depending on the climatic nature of the zone. Based on this, a good knowledge of the climatic parameters such as solar radiation and ambient temperature is important for understanding the total energy available for use by a PV system. Solar radiation has a very large impact on PV systems. A decrease in the standard solar radiation value (1 kW/m^2) by 50% decreases the output power of a PV module by 50%. However, temperature affects the PV output voltage inversely in which high temperatures reduce the cell's voltage and consequently the output voltage of the PV system. According to [2] an increase in PV cell's temperature by 1° decreases PV module's power by (0.5–0.6)%.

In the Sultanate of Oman the peak electricity demand is expected to increase to 5691 MW in 2014 in comparison with 2773 MW in 2007. While, in 2010 the annual growth rate, was about 17.8%, and peak demand continued increasing due to the population growth and accelerated industrialization in Oman. The forecasted electricity generation in 2014 will be 24.0 TWh, and shortages in electricity are expected to occur in the near future if current trends continue. The natural gas production is 1,097,661 MNSCF in 2009. The government in Oman accounts for 29.16% of total gas production in 2008, while the remainder is used in oil-production and for export, and up to 92% of the natural gas is domestically used for producing electricity [3]. This situation shows that studies on renewable energy must be done for Oman in order to encourage investment in this filed. Such studies must start by assessment studies of renewable energy systems in terms of technical and economical aspects.

The Sultanate of Oman lies between latitude 16°40′N and 26°20′N and longitudes 51°50′E and 59°40′E which is in the solar belt. The climatic conditions are mainly desert in the north and subtropical in the far south. However, according to [4], the average solar radiation in Oman is 5.197 kWh/m^2/day and the daily

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sunshine duration is between 8.0 and 10.5 h [5]. Based on this, Oman has a very good potential for solar energy harnessing because of the long daily duration of sunshine hours and high levels of solar radiation. In other words the use of PV system is expected to be feasible and therefore, deep technical evaluation, feasibility and size optimization studies must be done for this zone [6].

Some PV system design and evaluation work done for Oman can be found in [7–10]. In [7] solar energy averages were predicted for 17 sites in Oman namely Khasab, Majis, Buraimi, Rumais, Mina Qaboos, Seeb, Rusail, Saiq, Sur, Fahud, Masirah, Yalooni, Marmul, Thumrait, Qairoon Hairiti, Salalah, Mina Raysut. The authors found that the average solar energy for these sites is 5.597 kWh/m^2/day. After that the authors used some intuitive methods to size the PV system's components. The authors found that the cost of energy produced by a PV system located in Oman is about 0.21 USD/kWh. However, in this research the authors did not state the availability of the designed system which makes us unable to judge the reliability of the proposed system. In [8] data from 25 sites in Oman were used in order to investigate the feasibility of PV systems in these sites. The authors claimed that the average solar energy for these sites is in the range of (4–6) kWh/m^2 day with the average value being equal to 5 kWh/m^2 day. After that the authors assumed a 5 MWp PV plant applied to each site and discuss its feasibility by calculating the cost of energy using RETscreen software. The authors reported that the cost of energy produced by such systems is (0.21–0.304) USD/kWh. In addition to that the authors used the capacity factor to technically evaluate the system and it was found to be in the range of (0.14–0.2). In [9] the choice of applying a standalone PV/wind/Diesel generator for rural area in Oman is assessed using HOMER. The result of this study shows that the proposed systems can displace diesel generation significantly and the economical benefits of the resulting hybrid systems depended on load and renewable energy resources. This means that the potential of the renewable energy sources (wind and solar) is not equal in Oman and thus, an optimization of the renewable energy sources' share in such a system must be done. Such an optimization provides design recommendations in order to achieve the desired feasibility and reliability levels. Other utilization of HOMER for investigating renewable energy system in Oman can be found in [10]. In this study the optimum size of renewable energy systems is determined by HOMER in order to be able to fulfil the electrical energy requirements of remote sites located in Hajer Bani and Hameed in the North of Oman, Masirah Island and the Mothorah area in the South of Oman. As a result, the costs of energy produced by the proposed systems were found to be 0.206, 0.361 and 0.327 USD/kWh for Masirah Island, Mothorah and HB Hameed, respectively.

From the reviewed work, we can find that most of the authors used HOMER or RETscreen softwares in their study despite the fact that these softwares only deal with monthly average data as input which may affect the accuracy of the results. This is to say that such an analysis must be done using hourly solar radiation and ambient temperature data in order to get accurate results. In addition to that most of the previous work used the costs of energy only to assess the proposed PV systems. Meanwhile other technical factors can be used such as the yield factor and capacity factor. Finally Sohar site which is the case study of this research has not been taken into consideration in all the reviewed work. Based on this the main objective of this paper is to present a techno-economical methodology to evaluate grid connected PV systems in Oman based on three factors namely capacity factor, yield factor and cost of energy. The analysis is done by MATLAB software using hourly meteorological data and a model for grid connected PV system. Finally a comparison of the obtained results with other works is done. This work is based on hourly meteorological data provided by Sohar University.

Solar energy potential in Sohar

In this research data for 2 years (2011–2012) are used. These data contain hourly global solar radiation, diffuse solar radiation and hourly ambient temperature. In this research the global solar radiation as well as the ambient temperature are used. Fig. 1 shows the average daily global solar radiation, diffuse solar radiation and ambient temperature. From the figure the daily average total global solar energy is 6182 Wh/m^2, while the daily average total diffuse solar energy is 3289 Wh/m^2. In other words, Sohar zone has a very good solar energy potential and therefore, any PV system investment in this zone is expected to be very feasible. However, due to the nature of this site (desert site), the average ambient temperature is high as compared to other zones in the country. From Fig. 1 the daily average of ambient temperature is 32 °C. This is to say, if we use a PV module with a standard test condition with the ambient temperature being equal to 25 °C, a 3.5% reduction in the peak power occurs as the author of [2] claimed.

Modelling of grid connected PV system

Grid connected PV systems consist of a PV array and an Inverter. Recently a 3.08 kWp PV system has been installed in the campus of Sohar University. Therefore, in this research we assume that a 3.08 kWp PV system is installed at Sohar zone for future research work purposes. Table 1 shows the specification of the modelled PV system.

In order to simulate the assumed PV system, a series of hourly global solar radiation as well as ambient temperature data are used. These data are used to calculate the DC power generated by the PV array using a PV array mathematical model. Moreover, the AC power is calculated by considering the inverter efficiency (inverter mathematical model). After that an assessment of the

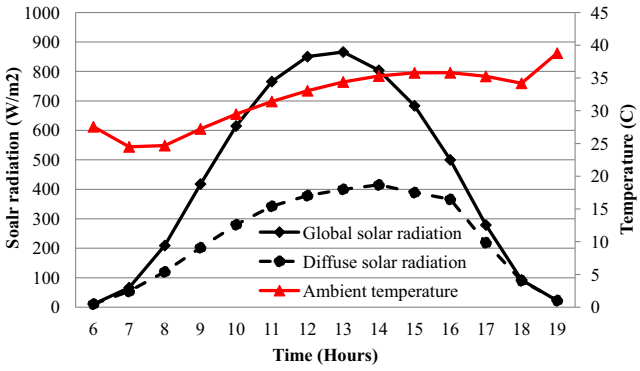

Fig. 1. Solar radiation and ambient temperature profiles for Sohar.

Table 1
Modelled PV system specification.

PV array	
PV module rated power (22 modules)	140 Wp (3.08 kWp)
Maximum voltage	17.7
Maximum current	7.91
Open circuit voltage	22.1
Short circuit current	8.68
Efficiency	13.9%
Temperature coefficient of Vo.c	−0.36%/k
Temperature coefficient of Is.c	0.06%/k
Inverter	
Rated power	3 kW
AC voltage	220–240
Efficiency	94.1%