

**ARTICLE**

# Design and Economic Analysis of a Grid-connected Rooftop Solar PV System for Typical Home Applications in Oman

**R. Ahshan\* A. M. Al-Hanshi M. A. Al-Naabi H. A. Al-Hashmi A. H. Al-Badi**

Dept. of Electrical &amp; Computer engineering, Sultan Qaboos University, Al-Khoud 123, Muscat, Oman

## ARTICLE INFO

*Article history*

Received: 20 July 2020

Accepted: 26 August 2020

Published Online: 30 November 2020

*Keywords:*

Rooftop PV system

System design

Temperature effect

Energy tariff

Economic analysis

## ABSTRACT

This paper presents a techno-economic investigation of an integrated rooftop solar PV system for typical home applications in Oman that can reduce the power consumption from the grid and export excess PV generated power back to the grid. Since renewable energy systems design technically depends on the site, this study selects a typical two-story villa (Home), in a site Al-Hamra, Oman. Temperature is one of the critical parameters in this design as it varies widely over the day and from one season to another in Oman. With the effect of temperature variation, the PV system has designed using system models for the required load of the home. The design process has included two main design constraints, such as the available rooftop space and the grid-connection availability for the selected home. This research also evaluates the economic feasibility of the design system considering the energy export tariff as per the Bulk Supply Tariff (BST) scheme in Oman. The design outcome reveals that the designed PV system can supply the load energy requirement in a year. In addition, the rooftop solar PV system can sell surplus energy back to the grid that generates additional revenue for the owner of the system. The economic performance indices such as payback period, internal rate of return, net present value, and profitability index ensure the financial feasibility of the designed rooftop solar PV system for the selected home.

**1. Introduction**

The negative impacts of the fossil fuel-based power generation and quick depletion of fossil fuel reserve are the key factors of increasing renewable-based power generation applications and integration. The renewable energy sources offer advantages, such as they are locally and freely available, sustainable, and environmentally friendly. On the contrary, the load demand around the world is significantly increasing every year. Therefore, significant momentum has seen in developing modern power network

infrastructures such as smart grids and microgrids using renewable energy sources over the last decades<sup>[1]</sup>. The primary source of generating electrical power in Oman is natural gas. In addition, the power demand in Oman is increasing by around 6%, and the emitting amount of harmful gas like CO<sub>2</sub> that comes out from the fossil fuel-based generation is undoubtedly high. Over the last 14-year period (2005-2018), the growth rate of annual average demand was 9%, while the growth rate of the annual average peak demand was 7.5%. Moreover, over the next 7-year (2019-2025), the expected growth rate of annual average

\*Corresponding Author:

R. Ahshan,

Dept. of Electrical &amp; Computer engineering, Sultan Qaboos University, Al-Khoud 123, Muscat, Oman;

Email: razzauqul@squ.edu.om

and peak demand is 5%<sup>[2]</sup>. Therefore, the Sultanate of Oman is currently integrating alternative green energy sources to contribute to electricity production, besides fossil fuel-based generations.

Literature reveals several investigations on designing rooftop PV system that supplies power either to the home load or to the utility grid depending upon the need. Authors in<sup>[3]</sup> present economic analysis considering the present Feed-in tariff scheme for grid-interactive rooftop PV systems for home applications in Turkey. The study suggests providing more incentives to deploy PV systems as it reveals attractive economic performance indices. Researchers in<sup>[4]</sup> have investigated the economic performance of grid-interactive home PV systems using an integrated economic adoption model that comprises of economic evaluation, analysis of profitability and sensitivity, and the probability distribution of levelized cost of electricity. The design and techno-economic study of a grid-interactive solar PV system design have been presented in<sup>[5]</sup>. This study reveals that the solar PV system application in Indonesia with Feed-in tariff scheme has a shorter payback period than the system without such a scheme. S. Yoomak et al. investigates the economic performance of rooftop PV system for various locations of Thailand considering different sizes and technologies of PV arrays<sup>[6]</sup>. It unfolds that the PV system with a capacity of 10 kW or less is economically viable if it installs with the Feed-in tariff scheme. Authors in<sup>[7]</sup> have presented the design and economic performance study of a rooftop PV system using PV\*SOL for a university building in Turkey. The design outcomes reveal that PV system can supply 13.2% of the building energy consumption annually, and the system can reach the breakeven point after 12.52 years. Reference<sup>[8]</sup> has demonstrated feasibility analysis of a grid-connected PV system, which indicates the cost competitiveness of the rooftop PV system with the support mechanism from the government and utility owners, such as Feed-in tariff scheme. Although the residential PV system shows satisfactory economic performance using Feed-in tariff as found by several researchers, reference<sup>[9]</sup> has presented an unsatisfactory economic performance of a residential solar PV system that considers multiple demands charge tariff. Such performance may arise due to the low solar irradiation or high cost of the technologies in the local market. Furthermore, economic analysis, optimal size and location, and hybridization of PV technologies for off-grid applications have been investigated and presented in<sup>[10,11]</sup>.

In Oman, about 97.5% of the total electricity generation comes from natural gas. Diesel is currently using to generate electricity for rural and remote areas. The Sultan-

ate of Oman has the compelling potential of utilizing solar and wind energy resources for renewable power production. The solar power potential in Oman is such that electricity production from this source can serve the country's power demand in addition to the significant export ability<sup>[12-15]</sup>. To these effects, the Sultanate is currently integrating renewable-based power generations in various scales for different applications. For example, the Authority for Electricity Regulation (AER), Oman has introduced Sahim I and Sahim II schemes that create the opportunity to integrate rooftop solar photovoltaic (PV) systems. The scheme Sahim I permits customers like large home and commercial premises owner to install and connect small-scale grid-interactive PV system with their own cost. This scheme also allows the system owner to export excess energy to the grid and receive pay back as per Bulk Supply Tariff (BST)<sup>[16]</sup>. Latter, Sahim II introduces in order to promote the large-scale implementation of the solar PV system. It aims to implement the small-size grid-interactive PV system for about 250000 rooftop installations, where the system cost comes from a funding agency and the premises owner upon an approved contract between the parties<sup>[16]</sup>.

The Ecohouse at the Sultan Qaboos University in Oman is an example of an on-grid rooftop PV system application. This PV system has installed capacity of 20.4 kWp<sup>[17]</sup>. The other Ecohouse located at the campus of Nizwa University in Oman, which has a rooftop PV system with an installed capacity of 20 kW<sup>[18]</sup>. PV-system in both Ecohouses supply excess energy to the grid after meeting the house load in the daytime. However, the power requirement for the Ecohouses during the nighttime comes from the grid. In these projects, the designed houses are ecofriendly, which may have different characteristics compared to the typical Omani houses. A rooftop PV system for an office building has presented in<sup>[19]</sup>. Moreover, the economic analysis of these studies shows a more extended payback period that is not encouraging. Such economic results may arise due to the absence of any incentive or consideration of the Feed-in tariff scheme. This study illustrates the design and economic performance investigation of a rooftop PV system design for a typical Omani house. The economic evaluation in this study includes the current energy export tariff as per the Bulk Supply Tariff (BST) scheme that results in an encouraging economic performance compared to the study presented in<sup>[18]</sup>.

## 2. Research Methodology

### 2.1 Home Site Selection and Energy Consumption

In this study, a typical home, two-story villa, has selected

to design the rooftop PV system. The home locates in the Wilayat Al-Hamra (23°07'00"N 57°17'35"E) in the Dakhiliyah Governorate in Oman. The available rooftop area in this selected home is 300 m<sup>2</sup>, and around 40 m<sup>2</sup> is reserved from this area for the tanks and other uses; as a result, the total available area for the PV system is 260 m<sup>2</sup>. Moreover, the Mazoon Electricity Company, Oman, currently supplies the house load.

Designing the PV system requires energy consumption by the selected home. The energy consumption data for the home load is obtained from the Mazoon Electricity Company, Oman. Figure 1 shows the home energy consumption for each month for the year 2017. The total load consumption for the selected home is 37.23 MWh/year. The average energy consumption by the home load is 102 kWh/day. The home load consumes above the average level of energy consumption during May, June, July, August, September and October months in a year, while the energy consumption during the other month is below the average level. It also reveals that the home load consumes maximum energy in July. It is because July is one of the hottest months in a year and people occupancy at home likely higher. The lowest amount of energy consumption is in February because this is one of the coldest months in a year. Table 1 shows the frequently used list and quantities of devices and home appliances for the selected home. However, not all the devices and appliances are operating at the same time. All the devices and appliances operating at the same time requires the peak energy demand of 137 kWh, which does not practically happen. Therefore, design rooftop solar PV system aims to produce an average daily energy of 102 kWh.

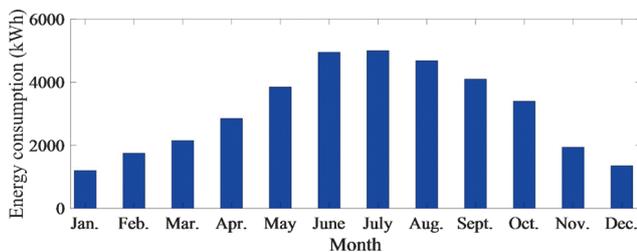


Figure 1. Monthly energy consumption by the load of the selected two-story villa

Table 1. Detailed of home appliances used in the selected two-story villa

Devices	Type/Specification	Quantity	Rated power (W)
Air conditions	1.5 ton	5	1510
	2 ton	2	1850
Tube light	4 feet	35	40
	2 feet	11	24

Fans	Ceiling Fans	14	100
	Exhaust Fans (20 cm)	6	275
	Exhaust Fan (25 cm)	3	305
Water Cooler	-	1	200
Freezer	-	2	300
Heaters	100 Liters	5	1700
	80 Liters	4	1300
Washing Machine	-	1	2500
Televisions	-	4	40
Iron	-	1	1000
Chargers	-	5	10
Water pressure	-	2	250

## 2.2 Solar Insolation and Temperature

Site solar irradiation and temperature directly influence the PV system output and its conversion efficiency. The accuracy of these data is essential in designing the solar PV system. The data for the Wilayat Al-Hamra for one year (2017) has been collected from the Directorate General of Meteorology and Air Navigation Department, Oman. Figure 2 illustrates the monthly average solar irradiation at the site of the selected home. The annual average solar irradiation for this site is 5.80 kWh/m<sup>2</sup>/day. The maximum solar insolation is 7.29 kWh/m<sup>2</sup>/day in May while the minimum solar insolation is 4.14 kWh/m<sup>2</sup>/day in January for this site. The data analysis also indicates that the peak sun hour for the selected site is 5.8 hours.

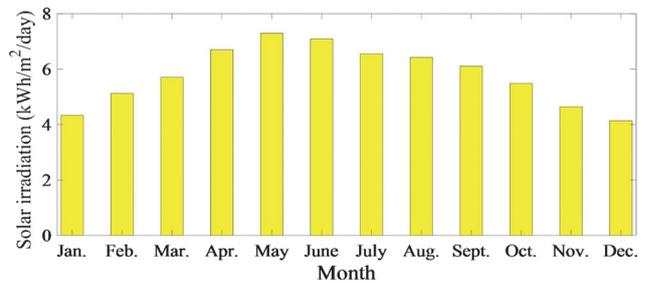
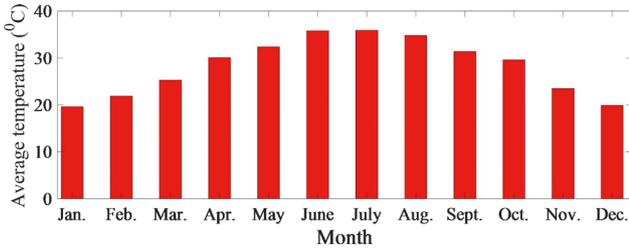


Figure 2. Monthly average solar irradiation for the selected home at the Al-Hamra site in Oman for the year 2017

Figure 3 demonstrates monthly average temperature variation at the Al-Hamra site in Oman. The highest average temperature observed as 35.9°C in July. Furthermore, the lowest average temperature noticed as 19.6°C in January. The hottest months for the selected site are May, June, July, and August, while the coldest months are January and December. The average temperature for each month of the year varies from 19.6°C in January to 35.9°C in July. It indicates a broader range of variation in temperature each day. Such variation in monthly temperature is sarcastic in designing solar rooftop PV system as it reduces the conversion efficiency of the PV arrays.



**Figure 3.** Monthly average site temperature data for the year 2017

**Table 2.** Permitted tariff (OMR/kWh) for residential consumers

Slabs	0-3000 kWh	3001-5000 kWh	5001-7000 kWh	7001-10000 kWh	Above 10000 kWh
Cost/kWh	0.01	0.015	0.02	0.025	0.030

### 2.3 Tariff Structure

Currently, in Oman, the residential customers pay their electricity cost based on the defined slabs, as shown in Table 2<sup>[20]</sup>. As per the Table 2, the owner of the selected house pays 0.01 OMR/kWh until the consumption 3000 kWh, while 0.015 OMR/kWh pays for the consumption between 3001-5000 kWh. However, if the selected house installs PV system, the system owner can export power to the grid as per the Bulk Supply Tariff (BST) structure presented in Tables 3 and 4<sup>[21]</sup>. BST, a component of Cost Reflective Tariff (CRT), charges the cost of capacity production of electricity demand requirement for the customers at different period<sup>[22]</sup>. BST scheme is different for the Main Interconnected System (MIS) and the Dhofar Power Systems in Oman. It is because of the different underlying charges. The selected home in this study follows the BST scheme of MIS. The BST has two main components, such as BST rate band, and BST rate. BST rate band defines peak or off-peak periods for different days in a week. Table 3 shows the BST rate band that has four rate bands such as off-peak, night-peak, weekday day-peak, and weekend day-peak. Moreover, it defines the periods, such as 12:00 to 15:59 from Sunday to Saturday as the weekday day-peak; while 2:00 to 11:59 and 16:00 to 21:59 define as the off-peak period for the entire week.

**Table 3.** MIS rate bands of the BST

Rate Band	Off-peak	Weekday day-peak	Night-peak	Weekend day-peak
Period	2:00 - 11:59 16:00 - 21:59	12:00 - 15:59	22:00 - 1:59 (Next day)	12:00 - 15:59
Days of week	Each day	Sunday - Thursday	Each day	Friday and Saturday

Table 4 represents the charge of electricity consumption for different periods along with specific months. It reveals that the charge of electricity consumption is higher during weekday day-peak from May to July because the load demand is significant at these months and defined period. In contrast, the lowest cost of electricity consumption is in between November and March. Table 4 also shows that the energy cost for some months does not depend on the period. It remains the same throughout the month, such as in April. It is important to note that MIS or Mazoon Electricity Company is charging to their consumers as per the BST since they are the energy producer, supplier or distributor. Similarly, any customer who may own the solar rooftop PV system, this customer can charge the Mazoon Electricity Company as per the BST for exporting energy to the grid. The economic analysis of the designed solar rooftop PV system incorporates this energy export tariff in this study.

**Table 4.** Per kWh charge (OMR/kWh) as per the BST

Months	Off-Peak	Week-day-Peak	Night-Peak	Week-end-Peak
January-March	0.012	0.012	0.012	0.012
April	0.014	0.014	0.014	0.014
May-July	0.016	0.067	0.024	0.038
August-September	0.015	0.026	0.021	0.019
October	0.014	0.014	0.014	0.014
November-December	0.012	0.012	0.012	0.012

### 2.4 Sizing and Design Model of the System

The DC power output of the PV array is determined as<sup>[23]</sup>

$$P_{dc} = \frac{E_{load}}{D_f H_{psh} N} \tag{1}$$

where  $P_{dc}$  is the PV power production in kW,  $E_{load}$  is the annual energy consumption by the home load kWh/year,  $D_f$  is the total derating factor for both the temperature and other subsystems,  $H_{psh}$  is the peak sun hour,  $N$  is the total number of days in a year.

To reflect the temperature variation effect on the PV generated power, the PV cell temperature,  $T_{cell}$  is calculated as<sup>[24]</sup>,

$$T_{cell} = T_a + \left( \frac{T_{NOCT} - 20^{\circ}C}{S_{NOCT}} \right) \times S_{site} \tag{2}$$

where  $T_a$  is the site temperature in  $^{\circ}C$ ,  $S_{site}$  is the average solar intensity in  $kW/m^2$ ,  $S_{NOCT}$  is the solar intensity

at standard testing condition (STC) in kW/m<sup>2</sup>,  $T_{NOCT}$  is the Normal Operating Cell Temperature (NOCT) of the PV module in °C at STC.

The decrement in module output power due to the site temperature variation as a percentage of the maximum power is calculated as

$$P_{mod} = \beta \times (T_{cell} - 25^{\circ}C) \quad (3)$$

where  $\beta$  is the reduction in module output power for per °C temperature change in %/°C. The derating factor because of the temperature variation,  $D_{f,temp}$  is calculated as

$$D_{f,temp} = 1 - P_{mod} \quad (4)$$

The total derating factor,  $D_f$  is calculated as

$$D_f = D_{f,temp} \times D_{f,comp} \quad (5)$$

where  $D_{f,comp}$  is the derating factors due to the DC rating on the PV module nameplate, inverters, module inconsistency, AC and DC wiring, and shading<sup>[23]</sup>.

The required area for the solar PV array system is calculated as

$$A_{pv} = \frac{P_{dc}}{\alpha S_{STC}} \quad (6)$$

where  $A_{pv}$  is the required area for the PV array in m<sup>2</sup>,  $\alpha$  is the module efficiency that is available in the manufacturer data sheet.

The number of modules,  $n_{mod}$  required for the PV panel is determined as

$$n_{mod} = \frac{A_{pv}}{A_{mod}} \quad (7)$$

where  $A_{mod}$  is the required area for each PV module and it is available in the manufacturer data sheet.

In order to determine the PV system output voltage in an acceptable limit at the inverter input, the effect of temperature variation incorporated to calculate the PV module output voltage. With the effect of site temperature variation, the voltage at the PV module output is computed as<sup>[25]</sup>

$$V_{mo} = V_{mo,STC} \times (1 - \kappa (T_{cell} - 25^{\circ}C)) \quad (8)$$

where  $V_{mo,STC}$  is the voltage at the module output at STC,  $\kappa$  is the decrement in voltage at the module output

for per °C temperature variation in %/°C.

## 2.5 Economic Performance Model

This section presents economic performance indices models to evaluate the economic performance of the designed solar PV system. Such economic indices are the payback period, net present value, internal rate of return, and profitability index<sup>[26]</sup>.

Payback period defines the period that is required to get back the invested funds into a project. This parameter is simple to find, yet, it provides some judgment on the economic value of the project<sup>[23,26]</sup>. The payback period is calculated as

$$\text{Payback period (PP)} = \frac{\text{Initial capital cost}}{\text{Annual cash inflow}} \quad (9)$$

The net present value (NPV) determines as the difference between the current value of the cash inflows and outflows related to the investment over a period. This economic index considers the time value of money and overcomes the drawback of the payback period index. The positive value of this parameter indicates the project profitable, whereas the negative value indicates the project in a net loss<sup>[23,26]</sup>. NPV is determined as follows

$$\text{Net present value (NPV)} = \sum_{n=1}^N \frac{C_n}{(1+r)^n} - C_i \quad (10)$$

where  $C_i$  is the total initial cost,  $C_n$  is the net cash flow for the period  $n$ ,  $r$  is the discount rate, and  $n$  is the number of years.

The internal rate of return (IRR) represents the discount rate for which the net present value turns to zero. Therefore, equation 11 can be derived from equation 10 to calculate the IRR for an investment. The higher IRR indicates the faster recovery of the invested funds and vice versa.

$$0 = \sum_{n=1}^N \frac{C_n}{(1+IRR)^n} - C_i \quad (11)$$

The profitability index (PI) defines as the ratio between the NPV and the initial investment cost<sup>[26]</sup>.

$$\text{Profitability index (PI)} = \frac{\text{Net present value}}{\text{Initial investment cost}} \quad (12)$$

### 3. Results and Discussion

This section discusses the implementation of the research methodology of designing and economic analysis of the rooftop solar PV system presented in the preceding section. The Matlab software package has been used to implement the method discussed. It also demonstrates the outcomes of the research. Moreover, the energy export tariff as per the BST has utilized to calculate the monthly return by the designed system. The Phono Solar PV module (PS300M-24/T) and the inverter (Solis-25K) have chosen, and their detail specifications have been utilized from the manufacturer datasheet.

#### 3.1 Design of Rooftop Solar PV System

The rooftop solar PV system for a typical villa type home is designed to supply the energy requirement of the loads in the home. The total amount of energy required by the load is 37.23 MWh/year, the average daily energy required is 102 kWh for the home load, and Figure 1 referred to the monthly average load demand for the selected home. The designed solar rooftop PV system ensures the delivery of the total energy requirement of the selected home.

With the equations 2-5, the effect of varying temperature has been incorporated in the designed solar PV system by computing the derating factor due to the site temperature variation. Figure 4 illustrates the monthly derating factors variation in a year. It indicates that the PV system output varies in a broader range due to the temperature fluctuations. The hottest months, June reveals the lowest derating factor, 0.8583. It reveals that the output of the PV system can be decreased by 14.17% from its max value in June. On the other hand, the coldest month, January reveals the highest derating 0.9650. This derating factor reveals that there is a 3.5% reduction in PV output power from its max value in January. The mean derating factor due to the temperature variation,  $D_{f,temp}$ , is determined as 0.9077. The mean derating factor for the other subsystems,  $D_{f,comp}$  is calculated as 0.77 and obtained from the Reference [25]. With the effect of temperature variation and other system components together, the total derating factor,  $D_f$  has found as 0.6989 using equation 5.

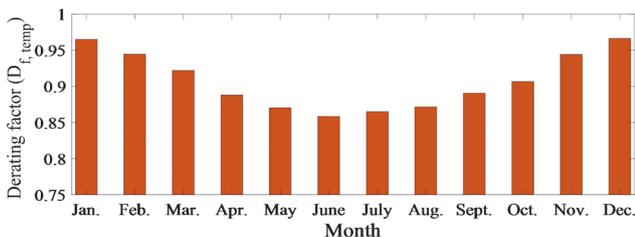


Figure 4. Monthly derating factor variations for the temperature variation

The DC power  $P_{dc}$  for the designed solar PV system has found to be 25.2 kW using equation 1. The required area to install this 25.2 kW PV system has calculated considering the module efficiency of 15.46%, as per the manufacturer datasheet, and 1 kW/m<sup>2</sup> solar intensity at STC. Equation 6 calculates the required area for the rooftop solar PV system as 163 m<sup>2</sup>. Each module requires an area of 1.96 m<sup>2</sup> as per the manufacturer datasheet. Equation 7 calculates the number of modules required for a 25.2 kW PV system, and it is found as 84.

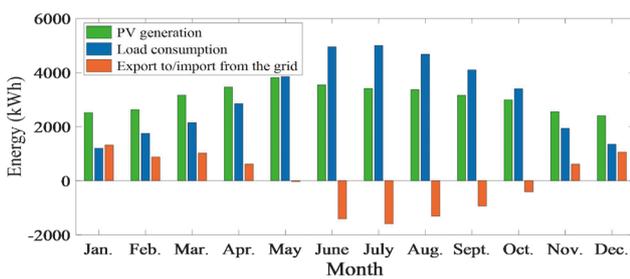
Table 5. Output voltage of the module considering the effect of temperature

Weather conditions	Monthly average temperature	PV cell temperature, $T_{cell}$	Module rated output voltage at STC	Output voltage of the module considering temperature effect	Module numbers per string
Coldest month	19.6°C	33.13°C	36.7 V	35.715	6 - 23
Hottest month	35.9°C	57.95°C	36.7 V	32.90	6 - 24

According to the manufacturer datasheet, the input voltage range of the selected inverter is 200V to 800V, which has been used to find out the module arrangement in the PV system. At STC, the module rated output voltage is 36.7V. Equation 8 calculates the module output voltage considering the effect of the site temperature variation. Table 5 reveals detailed about the module output voltage and the possible arrangement of PV modules in a string for two boundary conditions, such as the hottest and the coldest month in a year. The outcomes reveal that the module output voltage reduces because of the higher PV cell temperature compared to the STC PV cell temperature for two extreme conditions. The significant reduction in the PV module voltage has observed during the hotter months of the year. This outcome indicates that the hottest condition is the worst-case scenario, which is a good choice to determine module numbers of the string. The module output voltage reduces due to the hottest condition to 32.90V. It suggests that the range of module numbers that are possible to connect in a string as 6 - 24. Since the rated input voltage to the inverter at the maximum power point is 600V, this study suggests constructing a sting with 17 modules in series. The designed solar rooftop PV system requires 84 modules. Thus, the PV system layout can contain 5 strings, with a 17 modules in each string. The contribution of the short circuit current by each string can be 8.60A, which can result in a total short circuit current by the designed PV system is 43A that may present at the inverter input. Since the short circuit capacity of the inverter is 93.6A (more than 43A), it is sufficient to take over the short circuit current that may supply from the de-

signed PV system.

Figure 5 demonstrates the monthly energy portrait of the designed rooftop solar PV system for one year. PV generation refers here to the monthly energy generation by the rooftop PV system. The monthly energy generation varies due to two main factors, such as solar irradiation variation and derating factors variation due to the change in monthly temperature. The load consumption is the energy required by the appliances and devices used in the selected home. The energy export refers here as the positive energy balance that the PV owner can sell to the grid. The energy import refers here as the negative energy that the home load consumes from the grid while the PV generation is not sufficient to serve the load.



**Figure 5.** Energy production by the designed PV system, home load consumption and energy balance detail

Figure 5 shows that the energy required by the home load is 1198 kWh, while the energy production by the designed PV system is 2513.53 kWh in January. The surplus energy in this month is positive 1315.53 kWh. The PV system owner can export this excess energy to the grid. The rooftop solar PV system designed in this study generate surplus energy in February, March, April, November, and December. In May, the energy balance between the PV generation and the load demand is only negative 33.48 kWh, which reveals that the PV system can generate almost the same amount of energy required by the load. Figure 5 reveals that the energy equity in June is negative 1407.25 kWh. The negative energy balance indicates that the PV generation is less than the energy demand by the load. Thus, the grid requires to supply this energy demand of the load. Similarly, July, August, September, and October reveal the same energy balance scenario. Furthermore, the total energy balance by the PV system over the year is close to zero. It indicates that the designed rooftop solar PV system is sufficient to generate the load demand for the selected home. However, the time of energy export to the grid is different from the time of energy import from the grid. Such a difference can generate extra money for the PV owner if the energy sell price is higher compared to the buying price of the energy.

Figure 5 also reveals variation in PV energy produc-

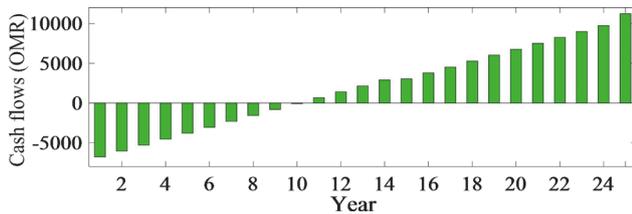
tion in each month because of the fluctuations in solar irradiance and the temperature-derating factor. Figure 2 has shown that the monthly average solar irradiances in May and January are 7.29 kWh/m<sup>2</sup>/day and 4.33 kWh/m<sup>2</sup>/day, respectively. The solar irradiance in May is almost 68.36% higher compared to January. It indicates that energy production in May would be 68.36 % higher compared to January. However, the actual energy production in May is 51.82% higher compared to January because of the rise in temperature in May. Such effect of the rise in temperature reflects in the PV system design by using the derating factor due to the temperature. Moreover, Figure 4 has demonstrated that May has a low value of the derating factor compared to January, which indicates a higher reduction in the PV output power during May.

### 3.2 Economic Analysis

This section presents economic performance indicators, such as payback period (PP), net present value (NPV), internal rate of return (IRR), and profitability index to evaluate the economic performance of the designed rooftop solar PV system. The renewable energy market analysis: GCC 2019 by the International Renewable Energy Agency (IRENA) reveals that the rooftop PV project implementation cost in 2018 was USD 700/kW (270.27 OMR/kW) in the UAE [27]. The start-up cost of the solar rooftop PV system of rated 25.2 kW has calculated as USD 17640 (6811 OMR). The initial cost comprises the system components and implementation costs. This study considers 0.22% of the initial cost as the operation and maintenance costs [28]. Both the initial investment and operating costs have used as the outflows cost of the study system. The inflows cost of the system comes from the cost of the energy generated by the solar rooftop PV system. The designed PV system exports 11.19 MWh/year to the grid among which 5.7MWh/year returned to the load when the PV system has no sufficient generation or during the nighttime, and directly supplies to the load is 26.04 MWh/year. The cost of energy supplies to the load and export energy to the grid combines as the cash inflows for the system. The energy export tariff presented in Tables 2 and 4 has used to calculate the cash inflows for the system [20-22]. The project lifetime is the same as the PV panel replacement period, which is 25 years.

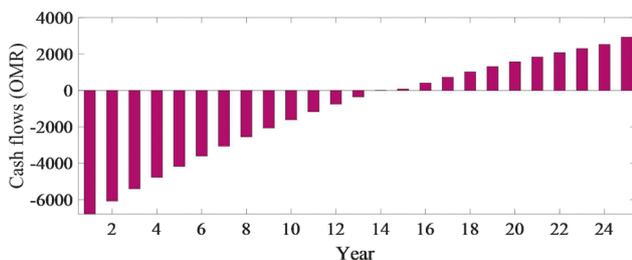
Figure 6 demonstrates cash flows for the rooftop solar PV system without considering the discount rate. The possibility of investing in this project without the bank loan is the reason for considering a zero discount rate. Figure 6 shows the positive annual cash flow at the eleventh year, which indicates the simple payback period of this project investment. Equation 10 calculates the net

present value (NPV) as OMR 1129, while equation 12 determines the profitability index as 1.66. Moreover, the internal rate of return (IRR) found as 9.65%. The economic performance indicators establish that the rooftop solar PV system is economically viable, which has a shorter payback period (11 years) and no need for borrowing money from the bank.



**Figure 6.** Cash flows for the designed rooftop solar PV system without discount rate

Figure 7 explains the performance of the cash flow for the rooftop solar PV system considering the discount rate,  $r = 5.5\%$ , which has obtained from one of the Banks in Oman. The discounted cash flow analysis reveals economic performance for the solar PV system owner in case the investment made through a bank loan. Figure 7 also indicates that the positive annual cash flow in the fourteenth year, and thus the payback period is 14 years. Equation 10 calculates the net present value (NPV) as OMR 2924, and equation 12 calculates the profitability index (PI) as 0.43. In addition, equation 11 determines the internal rate of return (IRR) as 3.93%. The discounted cash flow analysis demonstrates that the payback period is high. At the same time, the net present value and the internal rate of return is low, and the profitability index is less than one. These testify that the designed rooftop solar PV system is still economically viable, even if it implements through the bank loan. However, the investor return can be slower as compared to the upfront investment by the investor or the PV owner.



**Figure 7.** Cash flows for the designed rooftop solar PV system with a discount rate,  $r = 5.5\%$

#### 4. Conclusion

This paper has presented the design and evaluation of the economic performance of a grid-connected rooftop solar

PV system for a typical home in Oman. The effect of temperature fluctuations on the PV system power generation has been incorporated in the presented design method. The result has shown that the PV output power lessens naturally because of hot weather and a broad change in temperature at the site of the selected home. The rooftop solar PV system has shown the ability to export 11.19 MWh/year to the grid and to supply 26.04 MWh/year to the load directly. The designed PV system (25.2 kW) requires 163m<sup>2</sup> rooftop area that satisfies the space constraint considered in the design process. It has shown that the rooftop PV system needed 85 modules that have suggested arranging in 5 strings, where each string can have 17 modules connected in series. Such an arrangement also satisfies the manufacturer specification and requirements of the selected inverter and PV modules.

The economic analysis of this study has shown that the designed rooftop solar PV system for the selected home is economically feasible and productive. The discounted payback period was found for 14 years, whereas the simple payback period was found 11 years. The net present values with and without the interest rate were found positive. Moreover, the internal rate of return with and without the interest rates were found as 9.65% and 3.93%, respectively. The performance indicators have shown that the rooftop PV system is profitable and sustainable if the investment made either with or without considering the discount rate. Investments on the rooftop PV systems can reduce the grid dependency, and can contribute to supporting sustainable development in Oman. However, some other aspects such as power quality, flicker, harmonics, and voltage profile in integrating solar PV system need to investigate for operating the efficient and effective power system network. This study has shown that the solar rooftop PV system installation under the BST scheme is encouraging, as found in other studies<sup>[8,9,12]</sup>.

#### Acknowledgments

The authors gratefully acknowledge the support of the Mazoon Electricity Company, Oman, for providing necessary field data on load profiles. The authors also would like to acknowledge the Directorate General of Civil Aviation and Meteorology, Oman, for providing weather data.

#### References

- [1] Al-Badi AH, Ahshan R, Hosseinzadeh N, Ghorbani R, Hossain E. Survey of Smart Grid Concepts and Technological Demonstrations Worldwide Emphasizing on the Oman Perspective. *Appl. Syst. Innov.*, 2020, 3, 5.
- [2] OPWP's 7-YEAR STATEMENT (2019 - 2025), Ac-

- cess on July 7, 2020.  
<https://omanpwp.om/new/Documents.aspx?Pid=46>
- [3] A. C. Duman, O. Güler. Economic analysis of grid-connected residential rooftop PV systems in Turkey. *Renewable Energy*, 2020, 148: 697-711.
- [4] O. Ellabban, A. Alassi. Integrated Economic Adoption Model for residential grid-connected photovoltaic systems: An Australian case study. *Energy Reports*, 2019, 5: 310-326
- [5] E. Tarigana, Djuwaria, F. D. Kartikasari. Techno-Economic Simulation of a Grid-Connected PV System Design as Specifically Applied to Residential in Surabaya, Indonesia. *Energy Procedia*, 2015, 65: 90-99.
- [6] S. Yoomak, T. Patcharoen, A. Ngaopitakkul. Performance and Economic Evaluation of Solar Rooftop Systems in Different Regions of Thailand. *Sustainability*, 2019, 11, 6647.  
 DOI: 10.3390/su11236647
- [7] A. N. Akpolat, E. Dursun, A. E. Kuzucuoğlu, Y. Yang, F. Blaabjerg, A. F. Baba. Performance Analysis of a Grid-Connected Rooftop Solar Photovoltaic System. *Electronics* 2019, 8: 905.  
 DOI: 10.3390/electronics8080905
- [8] S. Moury, R. Ahshan. A feasibility study of an on-grid solar home system in Bangladesh. 2009 1st International Conference on the Developments in Renewable Energy Technology (ICDRET), Dhaka, 2009: 1-4.
- [9] M. Zeraatpisheh, R. Arababadi, M. S. Pour. Economic Analysis for Residential Solar PV Systems Based on Different Demand Charge Tariffs. *Energies* 2018, 11: 3271.
- [10] A. Maleki, M. A. Nazari, F. Pourfayaz. Harmony search optimization for optimum sizing of hybrid solar schemes based on battery storage unit. Available online 9 April 2020.
- [11] G. Zhang, Y. Shi, A. Maleki, M. A. Rosen. Optimal location and size of a grid-independent solar/hydrogen system for rural areas using an efficient heuristic approach. *Renewable Energy*, 2020, 156: 1203-1214.
- [12] A. H. Al-Badi, A. Malik, A. Gastli. Sustainable energy usage in Oman-opportunities and Barriers. *Renewable and Sustainable Energy Reviews*, 2011, 15: 3780-8.
- [13] Authority for Electricity Regulation - Oman, Study on renewable energy resources in Oman-Final Report by COWI and Partners LLC, Muscat, 2008.
- [14] S. AL-Yahyai, Y. Charabi, A. Gastli, S. Al-Alawi. Assessment of wind energy potential locations in Oman using data from existing weather stations. *Renewable and Sustainable Energy Reviews*, 2010, 14: 1428-1436.
- [15] R. Ahshan, A. Al-Badi, N. Hosseinzadeh, M. Shafiq. Small Wind Turbine Systems for Application in Oman. 2018 5th International Conference on Electric Power and Energy Conversion Systems (EPECS), Kitakyushu, Japan, 2018: 1-6.  
**DOI: 10.1109/EPECS.2018.8443520**
- [16] <https://aer.om/en/sahim>. Accessed on July 9, 2020.
- [17] Ecohouse.om: Solar Energy - Eco House Oman. Available from URL:  
<http://www.ecohouse.om/solar-energy/>
- [18] Unizwa.edu.om: EcoHouse Design @ University of Nizwa. Available from URL:  
[http://www.unizwa.edu.om/ecoHouse/home.php?op=en\\_ener](http://www.unizwa.edu.om/ecoHouse/home.php?op=en_ener)
- [19] M. H. Albadi, R. S. Al Abri, M. I. Masoud, K. H. Al Saidi, A. S. Al Busaidi, A. Al Lawati, K. Al Ajmi, I. Al Farsi. Designing up to 50 kW Solar PV Rooftop System. ICSGCE 2014 Conference of Smart Grid and Clean Energy, Sharjah, UAE.
- [20] <https://mzec.nama.om/en-us/Pages/tarifftype.aspx>
- [21] <https://mzec.nama.om/en-us/Pages/solarpower.aspx>
- [22] Authority for Electricity Regulation (AER). Cost Reflective Tariff (CRT). Muscat Electricity Distribution Company (MEDC) 2018.
- [23] R. Ahshan, R. Al-Abri, Al-Zakwani, N. Ambu-saidi, E. Hossain. Design and Economic Analysis of a Solar Photovoltaic System for a Campus Sports Complex. *International Journal of Renewable Energy Research*, 2020, 10(1): 67-78.
- [24] M.C. A. García, J. L. Balenzategui. Estimation of photovoltaic module yearly temperature and performance based on Nominal Operation Cell Temperature calculations. *Renewable Energy*, 2004, 29: 1997-2010.
- [25] G. M. Masters. *Renewable and Efficient Electric Power Systems*, Wiley, IEEE Press, 2013.
- [26] M. Zeraatpisheh, R. Arababadi, M. S. Pour. Economic Analysis for Residential Solar PV Systems Based on Different Demand Charge Tariffs. *Energies*, 2018, 11: 3271
- [27] IRENA, *Renewable Energy Market Analysis, GCC 2019*, International Renewable Energy Agency, Abu Dhabi, 2019.
- [28] W. Li, et al. Cost comparison of AC and DC collector grid for integration of large-scale PV power plants. *The Journal of Engineering*, 2017, 2017(13): 795-800.