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Feasibility of photovoltaic systems with grid-connected in residential building, Nizwa City, Oman using Homer software

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***Abstract*:**

Global warming is the most severe issue that the world will confront due to the implications of modern life techniques of industries and economic activities. The increase in Oman's population growth and industrial expansion has resulted in a rise in electricity demand of more than 240% during the last decade. Oman and many countries still widely use conventional resources, such as natural gas and diesel, to produce electrical power to balance global demand/supply dynamics. To mitigate the total dependence on the use of fuel to produce electricity by generators and reduce greenhouse gas emissions, alternative or renewable energy sources can be integrated with the public network to enhance the integration of electricity energy. Solar energy is one of the best clean energy sources that can be used for this purpose. Oman plans to achieve and reach the targets of 20% in 2030 and 35% - 39% in 2040 from renewable energy sources and reduce CO2 emissions at a rate of 7% by the year 2030. The primary goal of this research is to look at the possibilities of solar energy projects that can provide energy with a grid network and be an effective alternative in terms of economic and environmental feasibility in the future. The overall solar radiation average value at Oman's cities is more than 5.5 kWh/m2/day, and the average sunshine is 9 hours per day at the selected project area at Nizwa City. The study case is designed as a 10 kW PV solar system, battery 6.4 kWh-48V-125Ah and inverter with a grid network using data from Nizwa, Oman, using HOMER software and extracting the results after entering the required parameters, which is obtaining minimum cost of energy and determining the amount of CO2 emissions will be avoided. Two configurations of hybrid energy systems, including (PV/Grid) and (PV/Grid/ Battery), are analyzed and compared through optimization of energy sources in HOMER. The system's ideal solution is to use 24 PV solar panels connected to a 10-kW converter with a grid network. Homer software shows that the PV solar system works perfectly; it illustrates that the number of hours of operation is 4,362 hours/year. The PV system produces 14,756 kWh/year alone. The results demonstrate that combining a PV solar system and a grid system is viable, and it generates 21,712 kWh/year. It has economic and environmental feasibility, as it was found that the Cost of Energy COE per kilowatt is $ 0.039, compared to the standard system stand-alone of the grid system and PV/Grid/Battery, which is $ 0.052 and $ 0.059, respectively. Thus, the annual energy-saving cost of the hybrid system PV/Grid is $ 282.43. In addition, the Total Capital Cost is $ 6,000, and the Net Present Cost (NPC) is $ 11,102.05 for the optimal configuration of the PV/Grid system in terms of the environmental feasibility of producing 14,765 kWh/yrs, carbon emissions have decreased from 7,230,440 g to 4,413.01 g, with a difference of 7,226,026.99 g of carbon dioxide CO2. Thus, it can be avoided via this proposed hybrid system (PV/Grid). Ultimately, the Optimization result shows that the hybrid model (Grid/PV) can satisfy the total load demand of the residential building in Nizwa city, Oman with a low cost of energy.

Keywords: **PV system, Hybrid system, Solar energy, Economic and Environmental Feasibility, Homer analysis and optimization.**

1. Introduction

New and Renewable energy has become the common denominator in the era of global energy policy transition. Despite its existing economic weakness, its several strengths have attracted increasing attention as an alternative energy source. First, it has the potential to mitigate climate change, making the combustion process unnecessary through the use of natural energy sources, such as sunlight, wind, and Geothermal power [1].

Due to the global surge in energy consumption and the shortage of fossil fuels, formerly regarded as the primary energy source, the energy crisis has become a global concern. Furthermore, renewable energy has grown since 2011, which continued in 2019. The annual renewable energy capacity increases by source type from 2013 to 2019, and it achieved a record-breaking year in 2019, adding 200 GW (115 GW from solar PV, 60 GW from wind power, 15 GW from hydropower, and 10 GW from other renewable sources) [2]. The trend continuously increased to 256 GW in 2020 [3]. Developing countries have gradually surpassed developed ones regarding renewable energy demand and supply. More than forty percent of the world's total installed capacity for renewable energy sources is in only three countries: China, Brazil, and India, which is over 1000 GW.

Taedong Lee in [4] suggested that investment from the public and private sectors is crucial to enhancing renewable energy generation capacity in leading economies. In addition to regulation and economic incentive policies that can facilitate renewable energy capacity growth. Renewable energy sources are an alternative to fossil fuels for mitigating global warming [5].

The strategic geographical location of Oman makes it viable to harness renewable energy technologies on both smaller and larger scales to cater to the growing need for energy diversification, helps create a cleaner and sustainable environment, and supports economic diversification. In contrast, Oman (Muscat) experienced high amounts of pollutants particulate matter concentrations in 2021. Muscat, the region's most polluted city, ranks fifth in capital city pollution, with an annual average air pollutants concentration of 53.90 µg/m3, exceeding by more than ten times the World Health Organization (WHO) standard [6]. Thus, the government should pass a policy that encourages the usage and investment in renewable energy technology in both the commercial and residential sectors [7].

Due to the fast population growth and rapid increase of industrialization, world energy consumption has been rising drastically. To meet this high energy demand, traditional energy resources are no longer up to demand with notice to their challenges, such as high cost and greenhouse gas emissions. In the electricity sector, renewable energy has proven to be a reliable and sufficient alternative to traditional resources to meet this rapid increase in energy demand. Hybrid Renewable Energy Systems (HRESs) are defined as an integration of traditional fossil-based resources with renewable energy resources. The optimum size of HRES's components and equipment should be determined to assess minimum operation costs and investment and to meet the technical and emission constraints. One of the most critical points in HRES is the optimal planning of the equipment and components that make up the hybrid system, for example, the number, rating, and types of Photo-Voltaic (PV) arrays, Rating and number and capacity of PV converters, so that all of the constraints are satisfied, and the objective functions are minimized/maximized. The optimization technique and software are proposed and tested in the field. The global transition toward sustainable energy sources has prompted a surge in the integration of renewable energy systems (RES) into existing power grids. To improve the efficiency, reliability, and economic viability of these systems [8].

The Hybrid Optimization Model for Electric Renewables (HOMER) software is one of the most powerful tools for this purpose. HOMER has been deployed worldwide by many researchers to assess different hybrid systems.

Considering a basic solar PV system typically incurs high initial costs due to its modules, so the financial viability assessment and the extent to which the preliminary calculation and assumption are compatible with the outputs from the project in implementing such a system at a particular location with specific ambient conditions are vital. Therefore, the electrical engineers and concerned companies are facing challenges in the possibility of determining the type of feasibility of a new renewable energy source, especially solar energy projects, the possibility of installing the system, and calculating the energy output accurately using modern simulation software and comparing it with analytical calculations. The engineers are implementing solar energy projects (designing through analytical calculation only), later after completing them, they are surprised that the energy output from these projects is not satisfactory and does not match the calculations with which they were implemented at the beginning of their projects. This is what makes electrical companies not interested and venturing into solar energy projects. Thus, such issues were not leading the companies to invest and implement in this field. In addition, to achieve Oman's Vision 2040, it is pledged to reach 10% 2025 of installed capacity from renewable energy.

Numerous scholars have conducted analyses using HOMER and its functionalities. Hybrid Optimization of Multiple Electric Renewables, or HOMER, is the name of this initiative. The National Renewable Energy Laboratory NREL in the United States of America created this program so that remote, stand-alone, and distributed-generation power systems could be designed and evaluated. HOMER is a model for doing these three operations: simulation, optimization, and sensitivity analysis [9]. There are various studies on the optimal mixture of solar energy sources, but there are limited studies in Oman. This part will illustrate Omani and international papers relevant to my field of research in the Continent of Asia.

The results of the winning scenarios after implementing renewable energy projects showed that the quantities of harmful gases emitted are all reduced by acceptable rates and vary from one country to another compared to the base system. In addition, the results showed that solar energy projects have a positive impact and economic feasibility, and there is a decrease in net energy costs compared to current projects that use gas or diesel. However, it is noticed that in dual ways, the price of diesel and gas in some countries in the Middle East, especially in GCC countries, is lower, but not always; renewable energy plants still have a higher energy cost than conventional energy sources. As a result, some countries are still not interested in getting involved in the implementation of solar energy projects, and there are limited numbers of renewable energy projects implemented in these countries compared to other countries on different continents.

The scenario is probably slightly different in the African continent due to the lack of gas and diesel availability in African countries, which implement renewable energy projects as one of the alternatives to meet the required demand for electrical energy, making renewable energy projects have a high economic feasibility compared to the costs of importing gas or diesel to operate electricity generators such case conducted in Sudan [10]. However, there are challenges in implementing renewable energy projects in Africa at some point, especially after the outbreak of the Corona epidemic "COVID-19", to meet the energy challenges in the continent, which were hindered by the absence of competitive financing, the deteriorating state of the infrastructure of utilities on the continent, and the need to improve energy policy and legislative reform to promote investment in this sector. In European countries, due to the significant rise in fossil fuel prices, Brent crude in Europe reached, in October 2021, its highest level in five years at $ 84 a barrel, while spot natural gas prices increased by more than 500% year on year. On the other hand, demand has increased. The lack of investment in the fossil energy sector in Europe, in addition to severe weather phenomena, has led to a decline in the European Union's stock of natural gas from its usual rates, which further complicated the energy situation in Europe until it became a crisis. Therefore, European countries' challenges are multiplied regarding providing energy demand, so they have intensified their efforts to reduce carbon emissions rates, support the contribution of clean energy resources, and invest in renewable energy projects.

Summarizing results of studies for several configurations on Homer software is illustrated below in Table 1, which includes or involves details: References and publication year, project site, and findings.

Table 1: Published studies on Hybrid Energy Systems HES using Homer Software

Ref. [No.] Year		**Project Site**	**Configuration**	**Findings**
[11]	2020	Tunisia Kerkennah	Hybrid PV 12 kW, DG 1 kW and Grid	The proposed system was economically and environmentally beneficial, with a COE of $ 0,137 /kWh.
[12]	2021	Bangladesh	Case 1: Hybrid PV 50	Case 1 was the best case for residential buildings as

		Mohammadpur Dhaka	kW- Grid. Case 2: Hybrid PV 50 kW- Batt/Grid.	the electricity sold was more than the electricity purchased, and as no battery was connected, the operating cost was lower. NPC and COE were lower than in case 2. Case-1 meets the annual electrical load of the specific area with minimal losses and cheap OC.
[13]	2019	India, An Educational Institute	Hybrid Grid / PV in different sizes, starting from 1 to 150 kW	In a year, 36.64% of kWh energy is saved, which is around 53,918 kWh. So, it comes to 4,493 kWh per month. The net savings in Rupees are 8,95,384.50.
[14]	2017	India, Tamil Nadu, A rural Village	Hybrid PV 110 kW and DG 19 kW	The PV, DG, and battery system is the most cost-effective, with a total NPC of US $ 271,637 and a COE of US $ 0.23 / kWh. The reduction in CO_2 emissions is estimated at 242 tons of CO_2 / year and US$ $ 3140 / year collected from the Carbon Credit.
[15]	2022	Oman ALMazyouna	Hybrid PV, DG & Storage Batts.	There is a 28% reduction in harmful gases when using the fixed hybrid system, as compared to the basic system, NPC = $ 84.8 M, COE = $ 0.161 /kWh for the hybrid system, while they were higher for DG only, NPC = $ 99.4 M, COE = $ 0.188 /kWh

From the above literature, implementing a hybrid system will reduce the amount of CO_2 more than conventional systems. It also provides a low net present cost NPC and cost of energy COE compared to the existing system, which is grid stand-alone. Hence, implementing the grid-connected solar PV system will be the best solution to meet the demand in specific sites and reduce CO_2 emissions.

The above indicators are leading to thinking and contributed through study to this matter as seriously. And contribute to solving the main problem which PV solar systems are not intensive in Oman due to fewer projects of solar PV implemented, as well as Nizwa city has a power plant that is working on natural gas and currently it has been out of work and discontinued due to the expiration of contract operation.

2. Research Gap, Materials and Methods

This study aims to fill explicitly with investigation, implementing and proving the feasibility of integrating the PV system with the grid. Moreover, the general purpose of the study is to explore the possibility of implementing renewable energy sources such as solar energy with consideration of environmental and geographical data in Nizwa City in Oman.

Three key research activities were undertaken to meet the research objectives. The first one is to estimate the energy consumption of a residential building in Nizwa City, Oman. The estimation is derived from typical monthly electricity billing, which is then verified through the identification of conventional electrical appliances and their usage. The second part of the methodology is to design a solar photovoltaic system that could cater to the energy demand estimated for a household in Nizwa City. The last part of the research would be to perform a techno-economic assessment using HOMER software to determine the feasibility of integrating the solar PV system. The flowchart depicted in Figure 1 shows the overall process flow of the work undertaken for this research project.

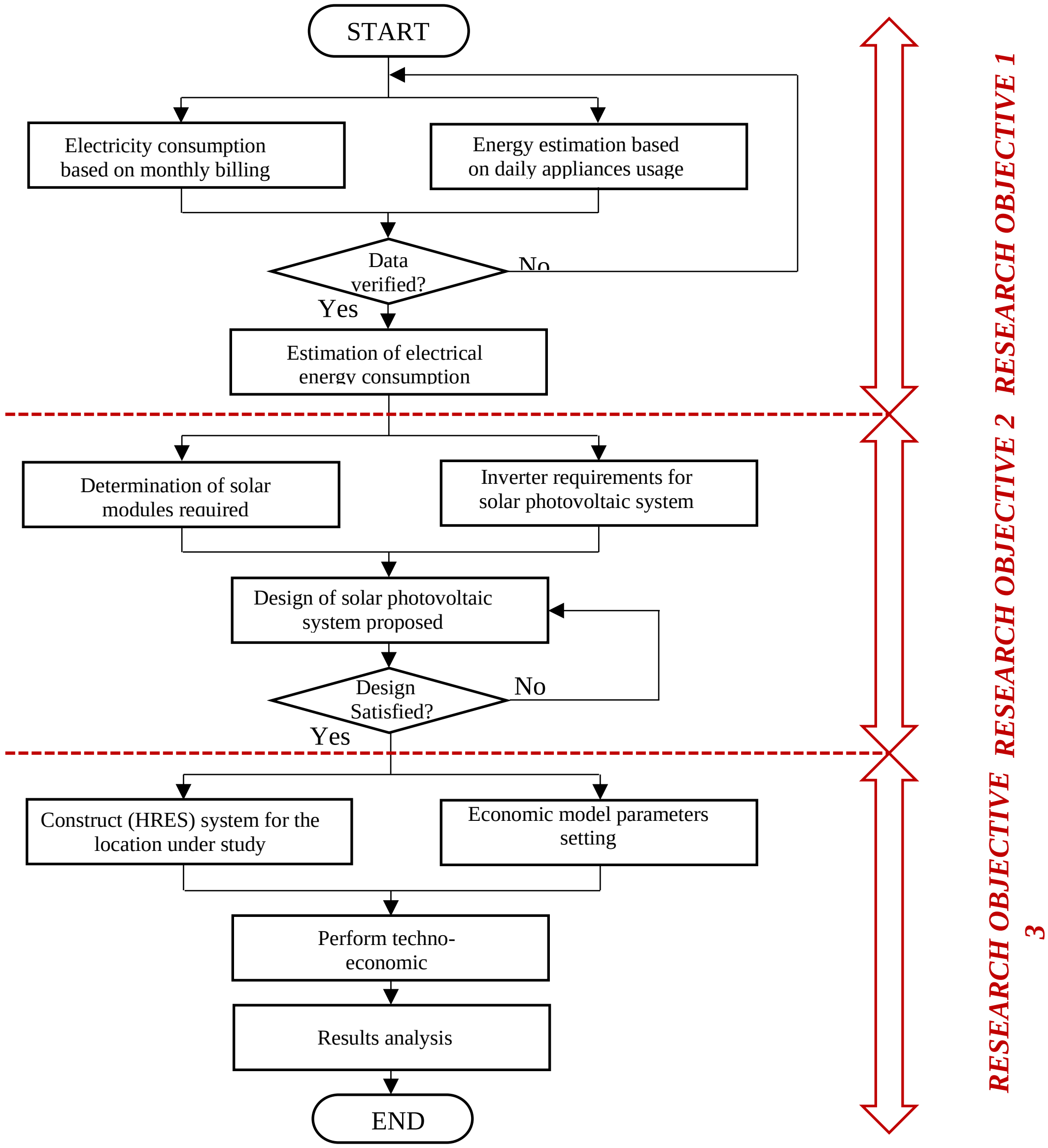

Figure 1: Flowchart of overall research methodology

2.1 Estimation of Electrical Energy Consumption

To assess the feasibility of using the solar PV system for a residential building in Nizwa City, the typical energy consumption needs to be ascertained first. For a residential premise, the load consumption can be determined via the monthly electricity billing, which can then give an estimation of the average electrical energy consumed per month and also per day. This information is especially important in determining the correct sizing of the solar PV system with the solar irradiance available in Nizwa City, to cater for the daily load consumption of a typical residential.

The energy consumption based on the billing is then compared with the estimation of electricity usage of a residential building based on the typical electrical appliances available in a house. To determine energy utilization within a residential premise, it is also equally important to have a clear understanding of the corresponding daily activities. This is because the variation in load consumption would be different based on the resident's activities and therefore various electrical appliances. For this reason, the estimation of the hourly and therefore daily electrical energy consumed can be made as accurate as possible.

By having the estimation of energy consumption for a typical residential building in Nizwa City, the sizing of the solar system can thus be determined. This estimation also would give an indication in terms of the cost involved for electricity consumption using an off-grid photovoltaic solar system and its corresponding payback period. Figure 2 shows the simplified flow in determining the typical electricity consumption of a residential premise, which would then be used as the main criteria in designing the solar photovoltaic system.

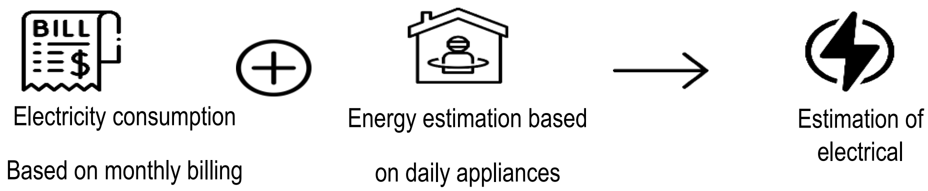

Figure 2: Work process in estimating energy consumption for a residential building in Nizwa City

Generally, the average electrical energy consumption for residential building in Nizwa city is 30 kWh per day. The amount of energy consumption is based on data collected from monthly tariff bills in 2023, as shown in Table 2.

Table 2: Bill details for the year 2022

Invoice Month	Consumption Per Month (kWh)	Charge Per Month (US$)
January	581	30.21
February	709	36.87
March	730	37.96
April	876	45.55
May	992	51.58
June	1080	56.16
July	1280	66.56
August	1177	61.20
September	1002	52.10
October	912	47.42
November	807	41.96
December	614	31.93
Total Annual	10,760	560
Average/month	~ 900	~ 47
Average/day	~ 30	~ 1.5

Assessment of the load profile of the typical residential building includes the various appliances, appliance wattage, and the number of hours the appliance will operate per day. Table 3 shows different loads with their operating power.

Table 3: Load Profile of Typical Residential Building

Appliance	Quantity	Unit Load (kW)	Maximum Demand (kW)
Lighting (4 Feet)	35	0.02	0.70
Ceiling Fan	8	0.05	0.40
Exhaust Fan	5	0.03	0.15
Air Conditioner	8	1.00	8.00
TV	2	0.02	0.04
Refrigerator (500 L)	2	0.07	0.14
Computer	2	0.02	0.04
Iron	2	0.50	1.00
Mobile Phone Charger	3	0.01	0.03
Rice Cooker	1	0.09	0.09
Water Filter	1	0.09	0.09
Washing Machine	1	0.10	0.10
		Total (kW)	~ 10

The total duration of daily power consumption time is divided into three durations of 8 hours. The amount of power utilized by different loads is shown in Table 4. The first duration is from 11:00 PM to 6:00 AM, consuming around 1 kW per hour. From 7:00 AM to 2:00 PM, it is 0.80 kW per hour due to the family members leaving home. From 3:00 PM to 10:00 PM, it is 1.95 kW per hour, comprising only air conditioners or fans operating during the first duration of the period. For the second duration, only fans and lights will be operating. In contrast, in the third period, all family members will be at home, so that all activities will be running, and it is considered the peak hours because most of the utilities will be operated according to daily activities. The total load consumption is summarized in Table 5.

Table 4: Amount of energy consumed by a house appliance throughout the day

Appliances	Lightings 4 feet	Ceiling Fan	Exhaust Fan	Air Conditioner	TV	Refrigerator 500L	Computer	Iron	Mobile Phone Charger	Rice Cooker	Water Filter	Washing Machine	Total kW
Total Nos.	35	8	5	8	2	2	2	2	3	1	1	1	11.000
Total (kW)	0.700	0.400	0.150	8.000	0.040	0.140	0.040	1.000	0.030	0.090	0.090	0.100	
Time													Total (kWh)
23:00	1 0.020	OFF	OFF	1 1.000	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	1.020
0:00	1 0.020	OFF	OFF	1 1.000	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	1.020
1:00	1 0.020	OFF	OFF	1 1.000	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	1.020
2:00	1 0.020	OFF	OFF	1 1.000	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	1.020
3:00	1 0.020	OFF	OFF	1 1.000	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	1.020
4:00	1 0.020	OFF	OFF	1 1.000	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	1.020
5:00	1 0.020	OFF	OFF	1 1.000	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	1.020
6:00	1 0.020	OFF	OFF	1 1.000	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	1.020
7:00	11 0.220	3 0.150	4 0.120	OFF	2 0.040	2 0.140	2 0.040	OFF	OFF	OFF	1 0.090	OFF	0.800
8:00	11 0.220	3 0.150	4 0.120	OFF	2 0.040	2 0.140	2 0.040	OFF	OFF	OFF	1 0.090	OFF	0.800
9:00	11 0.220	3 0.150	4 0.120	OFF	2 0.040	2 0.140	2 0.040	OFF	OFF	OFF	1 0.090	OFF	0.800
10:00	11 0.220	3 0.150	4 0.120	OFF	2 0.040	2 0.140	2 0.040	OFF	OFF	OFF	1 0.090	OFF	0.800
11:00	11 0.220	3 0.150	4 0.120	OFF	2 0.040	2 0.140	2 0.040	OFF	OFF	OFF	1 0.090	OFF	0.800
12:00	11 0.220	3 0.150	4 0.120	OFF	2 0.040	2 0.140	2 0.040	OFF	OFF	OFF	1 0.090	OFF	0.800
13:00	11 0.220	3 0.150	4 0.120	OFF	2 0.040	2 0.140	2 0.040	OFF	OFF	OFF	1 0.090	OFF	0.800
14:00	11 0.220	3 0.150	4 0.120	OFF	2 0.040	2 0.140	2 0.040	OFF	OFF	OFF	1 0.090	OFF	0.800
15:00	20 0.400	2 0.100	2 0.060	1 1.000	2 0.040	2 0.140	OFF	OFF	3 0.030	1 0.090	1 0.090	OFF	1.950
16:00	20 0.400	2 0.100	2 0.060	1 1.000	2 0.040	2 0.140	OFF	OFF	3 0.030	1 0.090	1 0.090	OFF	1.950
17:00	20 0.400	OFF	OFF	1 1.000	2 0.040	OFF	OFF	1 0.500	1 0.010	OFF	OFF	OFF	1.950
18:00	20 0.400	OFF	OFF	1 1.000	2 0.040	OFF	OFF	1 0.500	1 0.010	OFF	OFF	OFF	1.950
19:00	20 0.400	OFF	OFF	1 1.000	2 0.040	OFF	OFF	1 0.500	1 0.010	OFF	OFF	OFF	1.950
20:00	20 0.400	4 0.200	2 0.060	1 1.000	2 0.040	2 0.140	OFF	OFF	1 0.010	OFF	OFF	1 0.100	1.950
21:00	20 0.400	4 0.200	2 0.060	1 1.000	2 0.040	2 0.140	OFF	OFF	1 0.010	OFF	OFF	1 0.100	1.950
22:00	20 0.400	4 0.200	2 0.060	1 1.000	2 0.040	2 0.140	OFF	OFF	1 0.010	OFF	OFF	1 0.100	1.950
Total(kWh)	5.120	2.000	1.260	16.000	0.640	1.820	0.320	1.500	0.120	0.180	0.900	0.300	30.000

Table 5: Total load consumption per day

Time	Energy Consumed (kWh)	Suggested Power Source PV – Battery – Grid
23:00	1.02	Grid
00:00	1.02	Grid
01:00	1.02	Grid
02:00	1.02	Grid
03:00	1.02	Grid
04:00	1.02	Grid
05:00	1.02	Grid
06:00	1.02	Grid
07:00	0.80	PV
08:00	0.80	PV
09:00	0.80	PV
10:00	0.80	PV
11:00	0.80	PV
12:00	0.80	PV
13:00	0.80	PV
14:00	0.80	PV
15:00	1.95	PV
16:00	1.95	PV
17:00	1.95	Battery
18:00	1.95	Battery
19:00	1.95	Battery
20:00	1.95	Grid
21:00	1.95	Grid
22:00	1.95	Grid
Total (kWh/day)	**~30**	

Many components are required for solar system design, such as solar panels, structure base, combiner switch, charge controller, batteries, inverter, meters, electrical wires, and distribution box [16]. Thus, assessing daily consumption load is a significant part of designing solar systems. It was estimated that the total energy requirement per day from the whole system with an on-grid system is 30 kWh per day, and thus the monthly consumption is 30 kWh x 30 days = 900 kWh. Considering the degradation factor for array maintenance, mismatch, wiring losses, and other factors for elevating array operating temperature, the total safety or loss factor is assumed to be 1.25 [16]. Thus, the average energy production is 30 kWh × 1.25 = 37.50 kWh daily. Due to the 4.5 sun peak hours in the Nizwa area per day, the size of the DC power solar system can therefore be estimated to be 37.50 kWh / 4.5 h = ~9 kW.

2.2 Solar Photovoltaic System

Once the typical energy consumed by a residential premise in Nizwa City has been determined, the design for the HRES can then be initiated. The information on the electricity demand can be used in determining the size of the solar photovoltaic system required, the number of solar modules, the capacity requirements for the inverter, and eventually the overall design and connection for the system. The proposed design of the solar photovoltaic system for a residential premise would then be used in the HOMER software to perform the techno-economic assessment for HRES.

2.2.1 Solar Module Selected

Technology types, efficiency, and fixed land space determine the parameters for solar cell selection. Solar panel cost is the first factor people consider when selecting solar panels, and other parameters of solar panels must be considered, such as quality, energy efficiency, temperature coefficient, durability, size, and types of solar cells used. LONGi Solar LR6-72PE-370W has been chosen for this proposed system. It has a less derating factor of 80%, a lifetime of 25 years, a lower temperature effect on power at -0.380%/°C, and good efficiency of 19.10% with an acceptable capital cost of $ ١25 for this type of solar panel. The PV panel characteristics are listed below in Table 6.

Table 6: Technical Parameters of PV Panel

Parameters in (STD) 1000W/m^2, T = 25 °C & AM = 1.5	**Value**
Maximum Power (Pmax)	370 Wp
Maximum Power Voltage (Vmp)	39.4 V
Maximum power Current (Imp)	9.39 A
Open- Circuit Voltage (Voc)	48.3 V
Short-Circuit Current (Isc)	9.84 A
Module Efficiency STD (%)	19.1%
Operating Temperature (°C)	-40 ~ +85 °C
Maximum System Voltage	1000/1500 VDC (IEC)
Power Tolerance	0 ~ +3 %
Temperature Coefficient of Pmax	-0.380%/°C
Temperature Coefficient of Voc	-0.286%/°C
Temperature Coefficient of Isc	0.057%/°C
Capital Cost	$ ١25
Replacement Cost	$ 93.75
Maintenance and Operation Cost	$ 12.5
Size/Weight	1.94 m^2/26.50 kg
Lifetime	25 ears

2.2.2 Battery Storage Selected

Solar batteries are a reliable way to energize your house and essential appliances through extreme weather conditions and grid failures.

Batteries: Any extra power produced by the solar panels that aren't used at that time by the loads will be sent to a battery storage system. When the solar panels are not generating electricity, such as at night or in overcast conditions, the battery system saves the extra energy for later use. That suggested getting a power source from the battery for only 3 hours from 05:00 pm to 08:00 pm, as shown in Table 4, to generate (1.95 Energy Consumed x 3 hours x 1.1 degradation factor) = 6.4 kWh. The battery used LG-Chem RESU [6.4kWh] Lithium type, 48 V and 125 Ah, and a lifetime of 10 years.

2.2.3 Inverter Selected

The inverter is an essential part of the HRES, implemented as it converts the output DC power from PV panels to AC power that will flow and be utilized by the load. In choosing the appropriate inverter, certain factors should be considered, such as rated power output, maximum PV input power, efficiency, operating temperature, frequency output, and maximum open circuit voltage. Only one inverter, SolaX-X3 Hybrid10-1000-48-10kW, has been chosen for the proposed system with a capacity of 10 kW, power output per day from the solar system is 10 kWh, efficiency at 97%, and a lifetime of 25 years, as shown in the inverter's datasheet with the rating in Table 7.

Table 7: Inverter datasheet

Model	X3-Hybrid-5.0-D X3-Hybrid-5.0-N	X3-Hybrid-6.0-D X3-Hybrid-6.0-N	X3-Hybrid-8.0-D X3-Hybrid-8.0-N	X3-Hybrid-10.0-D X3-Hybrid-10.0-N
AC output				
Norminal AC power[VA]	5000	6000	8000	10000
Max. apparent AC power[VA]	5000	6000	8000	10000
Rated grid voltage(range)[V]	400V/230VAC;380V/220VAC			
Rated grid frequency[Hz]	50/60			
Norminal AC current[A](@230VAC)	7.2	8.7	11.6	14.5
Max.AC current[A]	8.0	9.6	12.8	16.0
Displacement power factor	0.8 leading...0.8 lagging			
Total harmonic distortion(THDi)	< 2%			
Load control	Being developed			
AC input				
Norminal AC power[VA]	5000	6000	7000	7000
Rated grid frequency[Hz]	50/60			
Rated grid frequency(range)[Hz]	47...53/57...63			
Norminal AC current[A](@230VAC)	7.2	8.7	10.1	10.1
Max.AC current[A]	8.0	9.6	11.2	11.2
Rated grid voltage(range)[V]	400V/230VAC;380V/220VAC			
Displacement power factor	0.8 leading...0.8 lagging			
Max. recommended DC power [W]	A:3000/B:3000	A:4000/B:4000	A:5000/B:5000	A:8000/B:5000
Max. DC voltage[V]	1000	1000	1000	1000
Norminal DC operating voltage[V]	720	720	720	720
MPPT voltage range [V]	200-950	200-950	200-950	200-950
MPPT voltage range[V](full load)	230-800	280-800	370-800	330-800
Max. input current [A]	11/11	11/11	11/11	20/11
Max. short circuit current [A]	14/14	14/14	14/14	23/14
Start input voltage [V]	180	180	180	180
Start output voltage [V]	300	300	300	300
No. of MPP trackers	2	2	2	2
Strings per MPP tracker	A:1/B:1	A:1/B:1	A:1/B:1	A:2/B:1
DC disconnection swtich	optional			
MPPT efficiency	99.90%	99.90%	99.90%	99.90%
Euro efficiency	97.00%	97.00%	97.00%	97.00%
Max. efficiency	97.80%	97.80%	97.80%	97.80%
Max. battery charge/discharge efficiency	97.60%/96.00%	97.60%/96.00%	97.60%/96.00%	97.60%/96.00%

2.3 Block Diagram

When solar power systems are connected to the grid, their operation remains virtually unchanged. Connecting solar systems to the grid is simple by providing and following the required constructed hybrid system using various photovoltaic PV panels, a solar grid-tie inverter, and a net meter. The electricity produced by the solar panels is direct current DC, but the solar grid-tie inverter changes it into alternating current AC that your home and the grid may use. Net meters process the current following and track how much electricity you supply to the grid and how much you get from it to calculate your monthly billing and credits with specified tariff rates.

As shown below in Figure 3, there are many parts required to design a solar system connected to the grid which are the PV array, DC isolator, inverter, meter, source of the grid, AC isolator, load protective devices, and wiring requirements are the primary components that make up a grid-connected PV system.

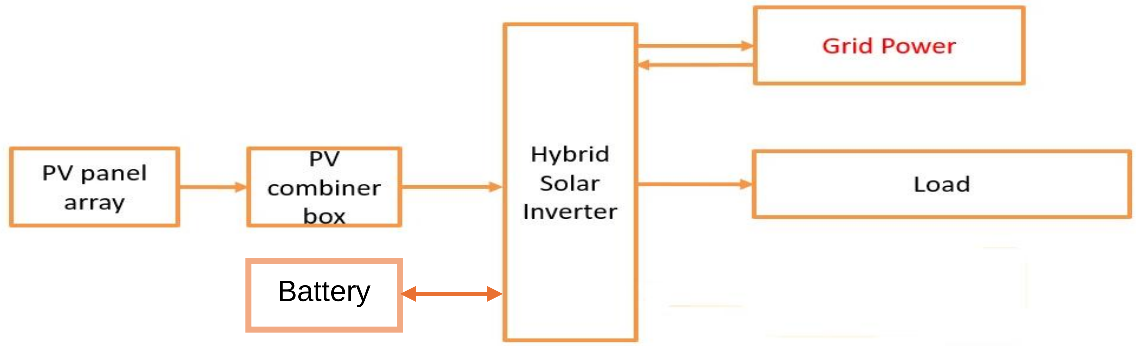

Figure 3: Block diagram

2.3.1 Design of Solar Photovoltaic System

The solar module chosen is a 370 W module rating with Voc of 48.3 V and Isc of 9.84 A, thus the number of PV panels required would be 9 kW / 0.370 kW = 24 panels. Two arrays are connected in parallel, and each set has 12 panels connected in a series mode. The following details are relevant calculations concerning the design of the solar photovoltaic system to be implemented:

- Wp = 370 W × 24 = ~9 kW.
- Voc = 48.3 V × 12 × 1.25 = 720 Vdc < max voltage system 1100 V in an inverter.
- Vmpp = 39.4 V × 12 × 1.25 = 591 Vdc < max of MPP voltage range 160-1000 V for the inverter.
- Isc = 9.84 × 2 × 1.25 = 24.60, a round up to 26, it has 2 inputs, each input is 13 A for the combiner unit and inverter.

2.3.2 Effect of Temperature

As the temperature of a PV panel increases above 25°C, its efficiency tends to decrease due to the temperature coefficient in the proposed PV panel (LONGi Solar LR6-72PE) being 0.286 %/°C. The coefficient measures how much the output power decreases for every degree Celsius above a reference temperature (usually 25°C).

Scenario 1: Increasing Temperature; based on the maximum temperature in the selected area at Nizwa City is 43.5°C. Thus, Voc = 720 Vdc – ((43.5 – 25) × 0.00286 × 720) = 682 Vdc.

Scenario 2: Decreasing Temperature; based on the minimum temperature in the selected area at Nizwa city is 12°C. Thus, Voc = 720 Vdc – (12 – 25) × 0.00286 × 496.2) = 747 Vdc.

For both scenarios, Voc is less than the (MPPT) maximum voltage system of 950 V in the inverter rating, so the solar module connection design is deemed acceptable.

2.3.3 Overall System Design

The proposed solar photovoltaic energy system is a small-scale solar generation plant combined with an on-grid supply, placed on the top roof of a residential building in an open area to receive more solar irradiation and continue PV energy generation. Solar HRES design contains the following parts: 24 pieces of PV panels 370 Wp and connected 12 panels with series, one unit of DC combiner box with 2 units of DC breakers with 13 A for each, one unit of inverter rated 10 kW - 230 V - 50Hz, one unit of meter, the grid source, one unit of distribution box with one unit of AC isolator and load and 1 battery 48 V - 125 Ah – 6.4 kWh, as shown in Figure 4.

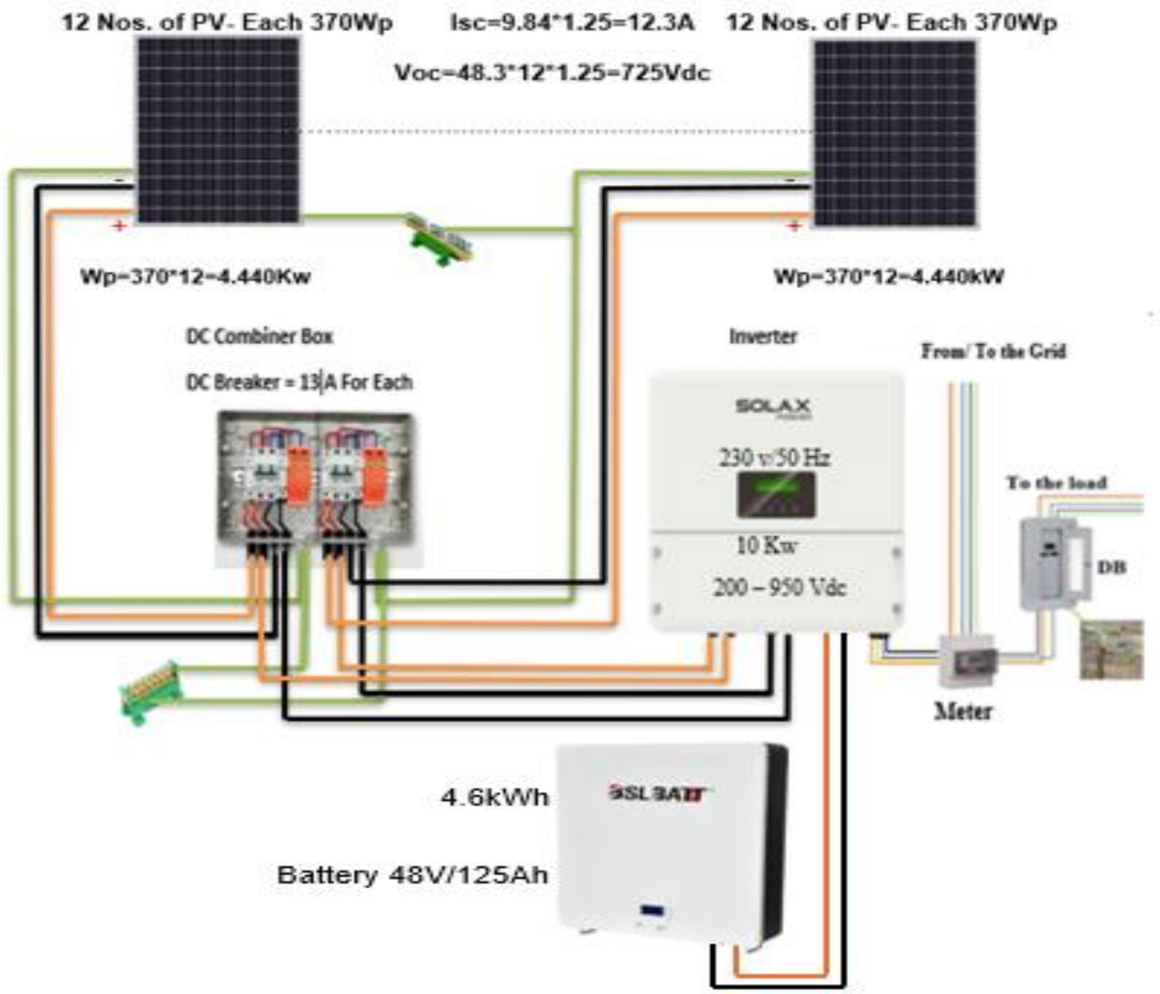

Figure 4: Solar On-Grid design system

2.4 Study Rigon (Nizwa-Oman)

Nizwa is one of the largest states in the Dakhiliyah governorate in Oman. Nizwa is roughly 140 kilometers - 87 miles and 1.5 hours from Muscat, Oman's capital. Around 72,000 individuals are expected to live there. Nizwa's location is between 22°56′0″N and 57°32′0″E, as shown below in Figure 5. Nizwa recorded a high temperature during the summer months. Nizwa City had an electricity peak demand of 191.50 MW annually in 2021 and increased the demand by 7% in 2022, which is 206.80 MW, based on data from Oman's electricity transmission company. Unfortunately, Nizwa City has not implemented any project for renewable energy sources till now, and there is no study paper on those sources in Nizwa City.

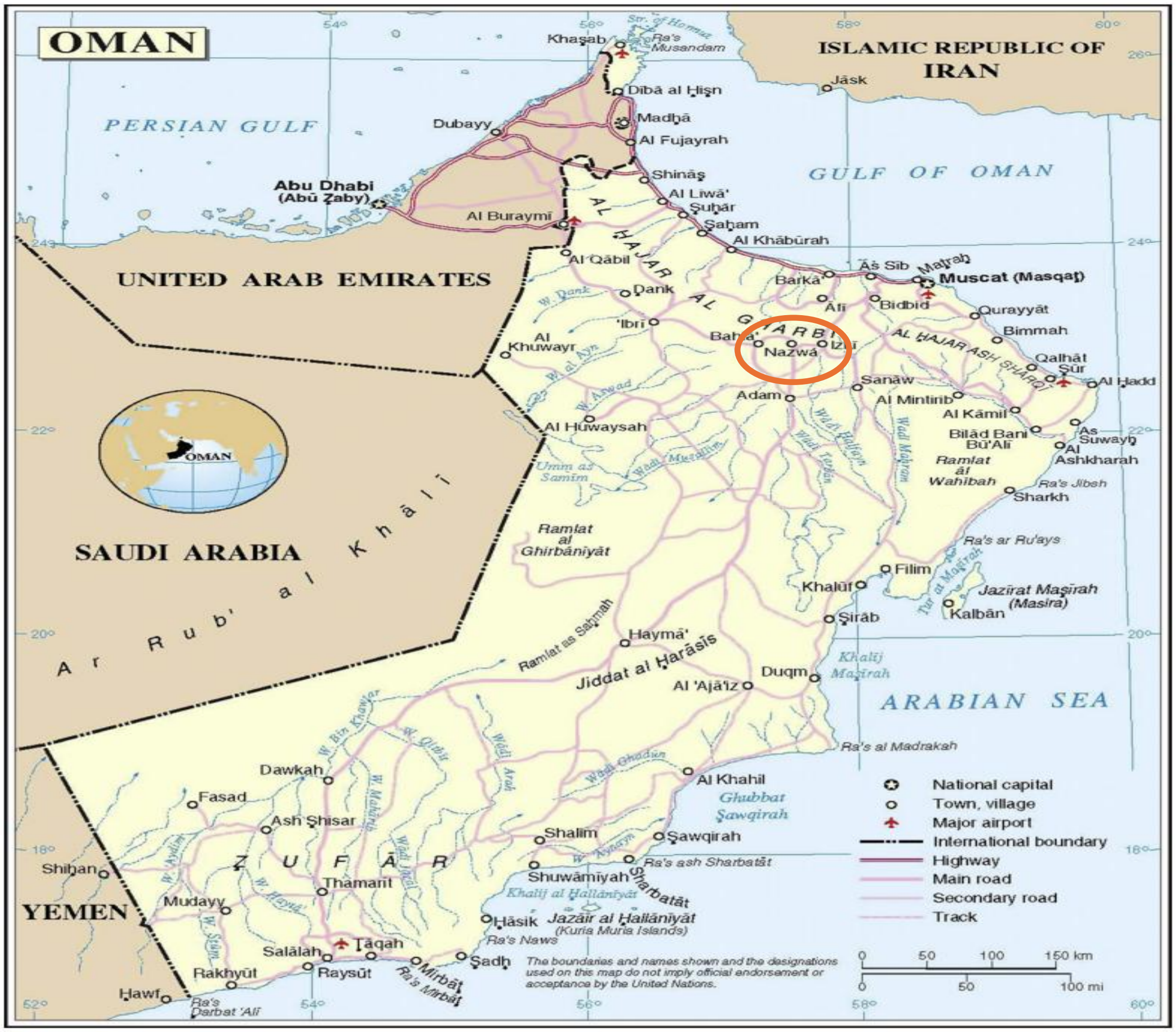

Figure 5: Location of Nizwa City

2.4.1 Geography and Climate in Nizwa – Oman

Mountains on all sides surround Nizwa. According to the Koppen climate categorization, Nizwa has an arid climate. Temperatures in January may drop to a pleasant 12 degrees Celsius, and the weather is generally a little cool from November through March. Extreme heat and dryness characterize the summers. Approaching 43.5 °C in June, the average high temperature for the year is 35 degrees Celsius. In addition, the average amount of rainfall per month in Nizwa is 10 mm.

2.4.2 Irradiation and Sunshine Hour Data in Nizwa – Oman

The monthly average Direct Normal Irradiance (DNI) measured at Nizwa-Manah station was 7.51 kWh/m2/day. A study by Atsu S.S Dorvloa and David B. Ampratwum shows Oman has more than eight sun hours per day [17]. Moreover, the study by Ali Al-Lawati computed the monthly average sunshine at 8 hours per day in Nizwa City [18]. Based on global solar atlas websites showed that Nizwa city has a high amount of Global Horizontal Irradiation (GHI) and Direct Normal Irradiance (DNI), 6.183 kWh/m2/day and 5.869 kWh/m2/day, respectively, with an optimum tilt of PV modules (OPT) is 25/180°.

Manah Site-1 in Nizwa is considered an ideal location for a stand-alone large-scale solar power facility. In Manah Site-1, solar insulation is assessed at 6.47 - 6.85 kWh/m2/day, and sunshine hours are around 9 hours daily. The data reading along with Direct Normal Irradiance (DNI) and Global Horizontal Irradiance (GHI) was taken from the study conducted by Oman Power & Water Procurement Co. [19]. The other latest study in June 2016 in Nizwa station showed results of (GHI) and (DNI) are ideal areas for conducting solar power projects [20].

2.4.3 Data sources of Solar radiation

Table 8 shows solar radiation and temperature data collected from the site in Nizwa City in 2022.

Table 8: Data on solar radiation from site measurement

March/2022 **Time**	**GHI** **kWh/m²/day**	**Temp** **°C**
06:00	3.85	20.30
07:00	4.88	22.20
08:00	4.99	25.90
09:00	5.72	26.20
10:00	5.92	27.10
11:00	6.91	28.90
12:00	7.83	30.30
13:00	7.22	31.20
14:00	6.92	29.10
15:00	5.76	28.80
16:00	5.34	26.30
17:00	4.6	25.40
18:00	2.89	24.90
Average	5.61	26.66

In addition, Solar radiation data from Homer software is shown below in Table 9 and Figure 6.

Table 9: Data of solar radiation (GHI) and temperature from Homer Software Metrology and Solar Energy Database

Month	**GHI** **kWh/m²/day**	**Temp** **°C**
January	4.33	19.22
February	5.12	20.68
March	5.71	24.29
April	6.70	28.81
May	7.29	32.84
June	7.09	35.02

July	6.55	35.16
August	6.42	34.44
September	6.10	31.98
October	5.48	28.27
November	4.64	24.10
December	4.14	20.94
Average	5.79	27.97

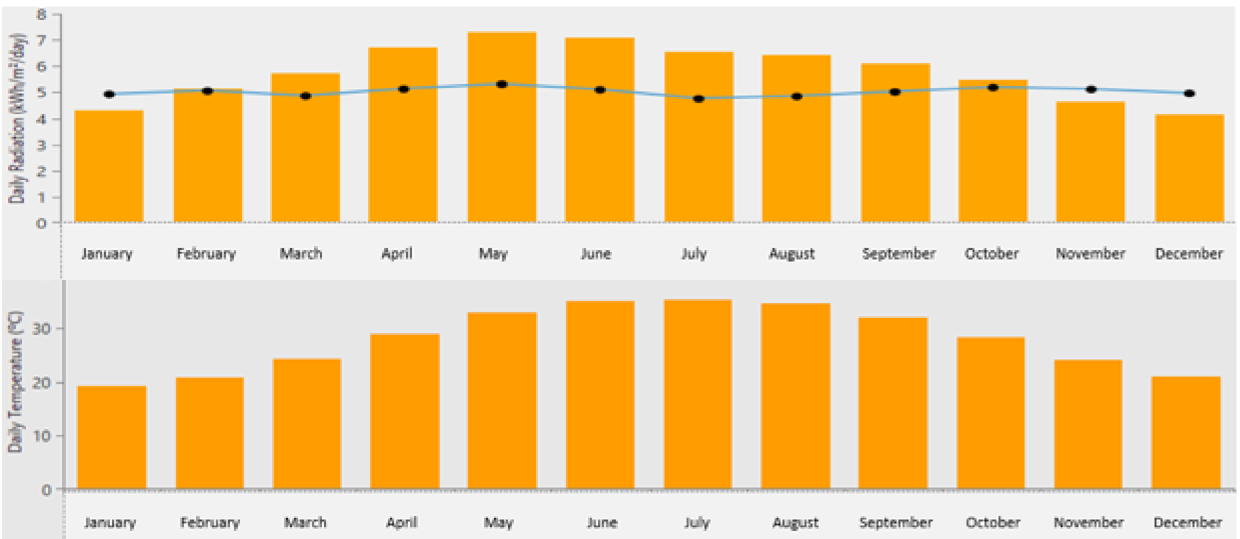

Figure 6: The monthly average value of global horizontal radiation and temperature

Table 10 compares the average solar radiation and temperature data from two sources collected from site measurements and the Homer Software Database.

Table 10: Comparison of the average of radiation and temperature data sources

Year 2022	**Homer Software - Metrology and Solar Energy Database**	**Site Measurements**
Average GHI ($kWh/m^2/day$)	5.79	5.61
Average Temp (°C)	27.97	26.66

2.5 Techno-Economic Assessment

Economic research is essential for proposing the best HRES part combination. This goal will be achieved through using the HOMER program. When constructing this structure, several important financial factors need to be considered.

2.5.1 Discount Rate

The discount rate is used to discount future cash flows when calculating the present value of an investment. It is applied to future cash flows because money earned in the future is less valuable than money earned now, based on the idea that money should earn more over time - a concept known as the "time value of money." It is widely used to calculate the Weighted Average Cost of Capital (WACC). It is an anticipated return on investment for businesses and investors. The discount rate chosen for this study is 7.50 percent as the data is categorized under Global Database's Oman [21].

2.5.2 Inflation Rate

Inflation is defined as an increase in the Consumer Price Index (CPI), a weighted average of the prices of different products and services. The index is composed of goods indicative of a typical consumption basket. Therefore, the index will include a wide range of goods depending on the nation and most people's consumption habits. Prices for certain products may decline while others increase; thus, the total value of the CPI will be decided by the weight of each item concerning the full basket. Annual inflation is the percentage change in the consumer price index from the same month of the previous year. (According to the National Centre for Statistics and Information) Oman's annual inflation rate has been cut to 2.06%, which will be used for this research.

2.5.3 Grid Power and Grid Sellback Price

The current energy tariff in Oman for residential usage is $ 0.052 per kWh, and the sell-back from the solar system to the grid is $ 0.066 per kWh [22].

2.6 Design Process for HOMER Software

The techno-economic assessment can be performed by modeling the (HRES) using HOMER software, following the procedures illustrated by the flowchart indicated in Figure 7.

2.6.1 Circuit and Operation

Figures 8 and 9 present two schematic diagrams of a nine kW-PV solar panels model (LONGi) Solar LR6-72PE-370 W with a 10-kW inverter model (SolaX10) and battery as part of a long-term energy system. In the first configuration, the PV module generates DC electricity linked to the inverter and converts it to AC power to feed the load with the grid system. This configuration provides for the most efficient and effective use of the produced electrical energy, resulting in a decrease in the use of energy from the grid. The system also allows the draw and export of energy from or to the grid for a more efficient manner of controlling the generated electricity, resulting in a shorter payback period and providing a versatile and readily maintained system that may be used in a residential building as consumption daily of 30 kWh/day as illustrated in homer software as shown in Figures 10 and 11, thus as average load consumption of 1.25 kWh as described below in Figure 12. In contrast, in the second configuration, adding a battery to the previous design system with a specific rating to generate power and standing for three hours to clear (1.95 Energy Consumed x 3 hours x 1.1 degradation factor) = 6.4 kWh.

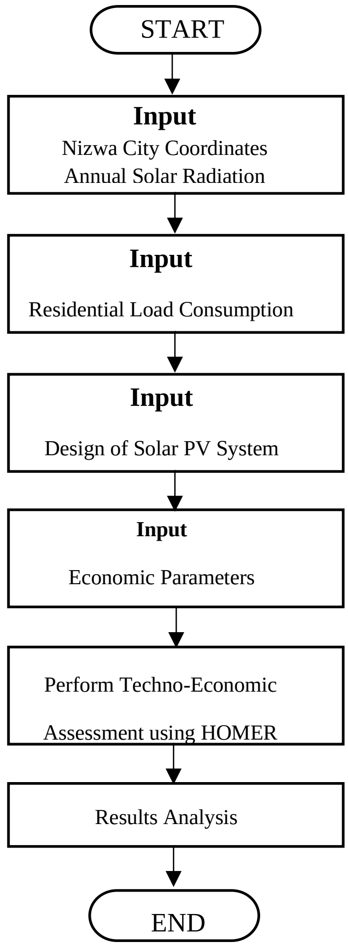

Figure 7: Process flow to perform techno-economic assessment using homer software

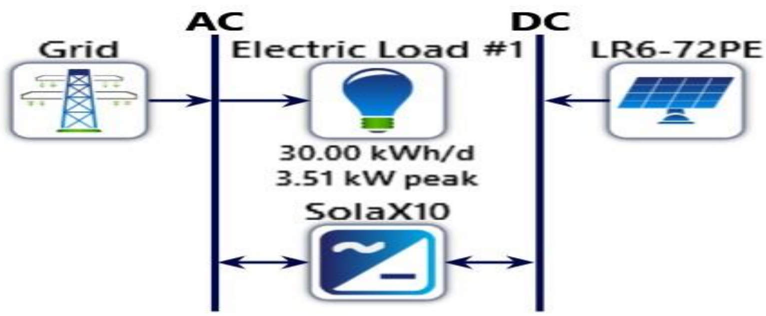

Figure 8: The schematic diagram for the PV/Grid system

Figure 9: The schematic diagram for PV/Grid/Battery system

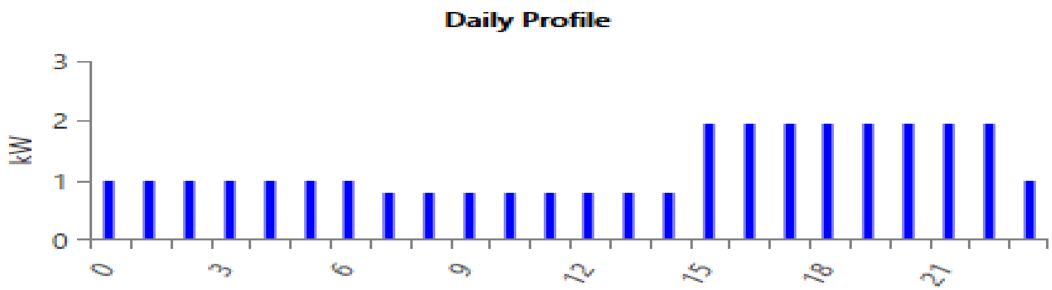

Figure 10: Daily load consumption in kWh

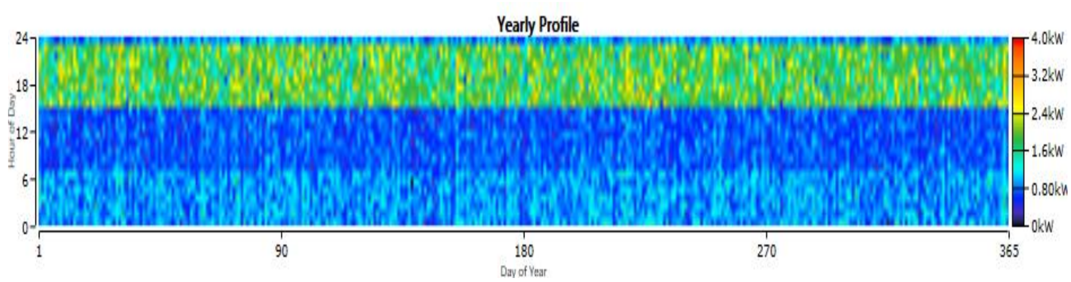

Figure 11: Yearly load consumption in kWh

Metric	Baseline	Scaled
Average (kWh/d)	30	30
Average (kW)	1.25	1.25
Peak (kW)	3.51	3.51
Load Factor	.36	.36

Load Type: AC DC

Figure 12: Average load consumption in kWh/d

Table 11 below shows the system architecture. This table illustrates that the optimized system consists of 24 PV panels, 0.370 kW each, with a total capacity of 9 kW, one unit of the inverter of 10 kW, and a battery LG-Chem RESU [6.4kWh] Lithium type, 48 V and 125 Ah.

Table 11: Systems Architecture

Configuration No.	Component	Name	Quantity
1	PV Panel	LONGi Solar LR6-72PE 370W	24
	System Inverter	SolaX X3 – Hybrid10 1000-48-10kW	1
	Grid	-	-
2	PV Panel	LONGi Solar LR6-72PE 370W	24
	System Inverter	SolaX X3 – Hybrid10 1000-48-10kW	1
	Grid	-	-
	Battery	LG-Chem RESU [6.4 kWh] Lithium, 48 V and 125 Ah	1
Dispatch Connected		HOMER Load Following	-

2.6.2 Feasibility Assessment of Hybrid Renewable Energy System

Capital Cost: It is calculated by adding the PV panel's system costs and the station's balance. Neither cost includes construction finance or financing costs, computed and applied separately via the fixed charge rate. Additionally, the expenses exclude a fund for debt payment reserves, which is assumed to be zero for balance sheet financing. The initial investment cost for each group is given independently in Table 12, and according to the capital cost of PV solar in Oman, which is around $ 0.334 US per Watt. Therefore, the system has 24 PV panels - 370 W each, and the total capital cost for PV solar is (0.334 x (24 x 370 W)), which equals $ 3,000.00. In addition, one piece of 10 kW of the converter is used, and the capital cost per kW is $ 300.00 US in Oman, and thus the total capital cost for the converter is (300.00 x (1 x 10 kW) which equals $ 3,000.00. Moreover, the capital cost for this type of battery is $ 1,800.00. Thus, the total capital cost for used components in the first configuration is $ 6,000.00, while it is quite high for the second configuration is $ 7,800.00.

Table 12: Capital cost summary

Configuration No.	Item	Size	Capital Cost
1	PV Panel	24 Panels, 370 W	$ 3,000.00
	Inverter	10 kW	$ 3,000.00
	Grid	-	-
	Total Capital Cost of the System		$ 6,000.00
2	PV Panel	24 Panels, 370 W	$ 3,000.00
	Inverter	10 kW	$ 3,000.00
	Battery	6 kWh Li, 48 V, 125 Ah	$ 1,800.00
	Grid	-	-
Total Capital Cost of the System			$ 7,800.00

Replacement Cost: The replacement cost is a decreasing fund factor for long-term replacements and repairs of important PV panel components. However, much effort is being made to develop more PV panel model efficiency worldwide. The replacement costs of PV solar and the converter are 75% of the capital cost for each. That is 75% of $ $ 3,000.00 is $ 2,250.00 for PV solar, and in the same case with a converter, 75% of $ 3,000.00 is $ 2,250.00, and 75% of $ 1,800.00 is $ 1,350.00 for the replacement cost for the battery. Thus, the total replacement cost for both configurations is illustrated in Table 13.

Table 13: Replacement cost summary

Configuration No.	Item	Size	Replacement cost
	PV Panel	24 Panels, 370 W	$ 2,250.00
1	Inverter	10 kW	$ 2,250.00
	Grid	-	-
		Total Replacement Cost of the System	$ 4,500.00
	PV Panel	24 Panels, 370 W	$ 2,250.00
	Inverter	10 kW	$ 2,250.00
2	Battery	6 kWh Li, 48 V, 125 Ah	$ 1,350.00
	Grid	-	-
		Total Replacement Cost of the System	$ 5,850.00

Operation and Maintenance (O&M) Costs: It includes all regular and unscheduled maintenance and operations costs associated with operating the PV panels system. Due to the various PV connections and installation designs, O&M expenses may vary. This enabled researchers to quantify the effect of different technical features on the cost of energy COE without considering the influence of operations and maintenance costs, which were exceedingly difficult to predict. While more work is being conducted to determine O&M costs for existing PV energy conversion systems, operating and maintenance costs are presented in Table 14 for this study. Considering O&M cost for all used components (PV solar, converter, and battery) is 10% of the capital cost. Thus, it is for the first configuration, 10% of $ 6,000.00 is $ 300.00, while for the second configuration, 10% of $ 7,800.00 is $ 780.00. The decided-upon O&M costs are theoretical, and to find a more realistic estimate, many factors should be considered. Such as the location of the plant, average salaries of technicians, and equipment costs if the equipment fails, thus making this estimate representative of the highest expected O&M cost and is subject to change and be reduced as the technology spreads wider and becomes cheaper to produce and repair.

Table 14: Operation and maintenance (O&M) costs summary

Configuration No.	Item	Size	O&M cost
	PV Panel	24 Panels, 370 W	$ 300.00
1	Inverter	10 kW	$ 300.00
	Grid	-	-
		Total O&M Cost of the System	$ 600.00
	PV Panel	24 Panels, 370 W	$ 300.00
2	Inverter	10 kW	$ 300.00
	Battery	6 kWh Li, 48 V, 125 Ah	$ 180.00

Grid	-	-
	Total O&M Cost of the System	$ 780.00

2.6.3 Techno-Economic Model

This section discusses techno-economic and environmental analysis to assess the feasibility of the optimal proposed energy system. Also, the techno-economic assessment was conducted on the Net Present Cost NPC, annual cost, annual benefit, cost of energy COE, and Levelized cost of energy LCOE. These functions are shown for the most applicable system, in which each PV panel contains a PV system with an on-grid.

The proposed PV energy system is a small solar generation plant combined with an on-grid system placed on the top roof of a residential building in an open area to receive more solar irradiation and continue PV energy generation. As reported earlier, the combined total capital cost for PV panels and inverter is priced at $ 6,000.00, replacement cost is estimated to be 75% out of the capital cost of $ 4,500.00, and operation and maintenance cost is approximately 10% out of the capital cost of around $ 300.00 with an estimated average lifetime of 25 years for the entire system per piece of equipment which allows for the system in continuously generate power as a reasonable duration of time to break even and start producing profit before any major repairs or changes are needed.

Considering that the main driving factor for increased production and thus, increased profit is the number of sun peak hours, which, despite intensive research, can still be unpredictable from time to time, especially daily. Establishing the system in open areas eliminates some of that uncertainty. Figure 13 from the HOMER function shows the amount of power the solar system generates throughout the day; the period between 08:00 am and 05:00 pm is around 10 hours per day. Moreover, Table 15 presents the electrical summary of solar panel performance during that period, including maximum power output per day, number of hours of operation, and total annual production. According to the table, the annual total energy production is estimated at 14,756 kWh/year within 4,362 hours.

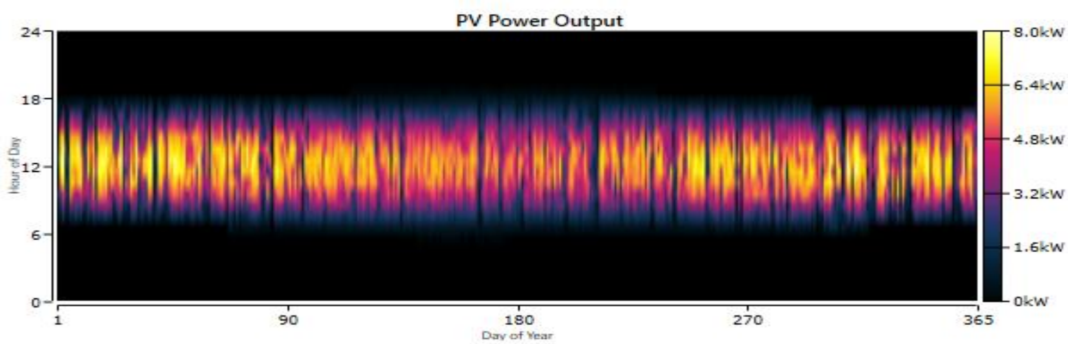

Figure 13: PV Power output kW through a day of the year

Table 15: Electrical data summary for solar photovoltaic system

Quantity	Value	Unit
Rated capacity	9	kW
Maximum Output	7.89	kW
Hours of Operation	4,362	hrs/yr
Mean Output	40.40	kWh/day
Annual Total Production (From Solar PV)	14,756	kWh/yr

System Converter SolaX X3–Hybrid10-1000-48-10kW works perfectly. The inverter works during the same period, and it matches and parallels PV solar panels from 08:00 am to 05:00 pm throughout the day, as shown below in Figure 14. Moreover, Table 16 shows the maximum power output per day, number of hours of operation per year, power input and output, and power losses.

According to Table 15, the annual total energy production is 4,362 hours. The total energy taken from the setup each year is 14,431 kWh, whereas the real power fed into it each year is 14,756 kWh. Due to the inverter efficiency of 97%, the total energy lost in the device is 325 kWh/year. The number of losses is negligible, considering the amount of power the converter moves between the PV modules and the load.

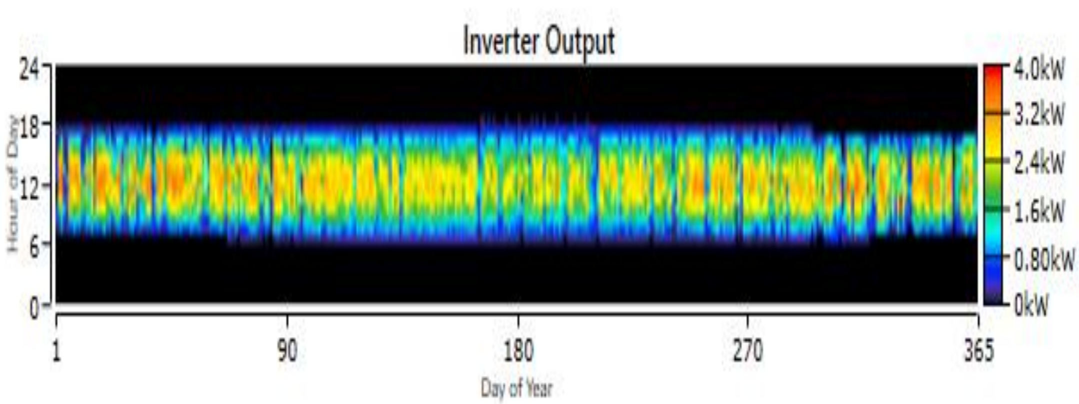

Figure 14: Inverter power output (kW) through day of the year

Table 16: Electrical data summary for inverter system

Quantity	Value	Unit
Maximum Output	7.72	kW
Hours of Operation	4,362	hrs/yr
Energy Out	14,431	kWh/yr
Energy In	14,756	kWh/yr
Losses	325	kWh/yr

3 Result Discussion

3.1 Optimal Configuration

HOMER can simulate various equipment possibilities under multiple limitations and sensitivities to optimize small power systems. The optimization result window will offer possible system configurations based on the Total Net Present Cost (TNPC) and Cost of Energy (COE). The system components are grouped in order of decreasing cost-effectiveness. Figure 15 and Table 17 below show the most optimized system according to HOMER.

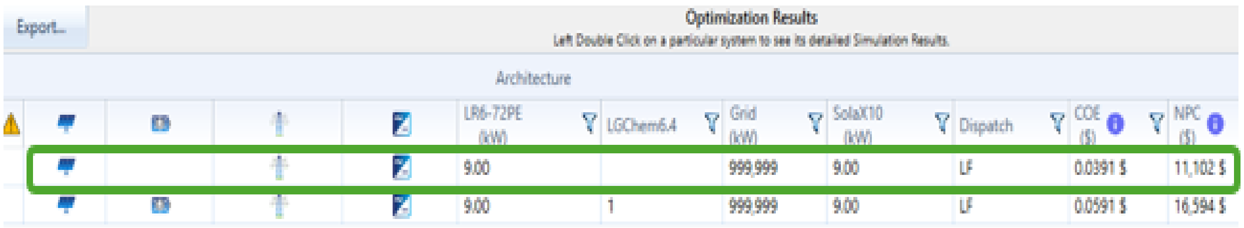

Figure 15: Optimization Result

Table 17: Optimal system result based on HOMER Simulation.

Configuration	Item	NPC ($)	Levelized Cost	COE ($)
PV	LONGi Solar LR6-72PE 370W			
Inverter	Inverter - SolaX X3 – Hybrid10-1000-48-10 kW	$ 11,102.00	$ / kW 0.040	$ 0.039
Grid	-			
PV	LONGi Solar LR6-72PE 370W			
Inverter	Inverter - SolaX X3 – Hybrid10-1000-48-10 kW	$ 16,594.00	$ / kW 0.060	$ 0.059
Battery	LG-Chem RESU [6.4 kWh] Lithium, 48 V and 125 Ah			
Grid	-			
Dispatch (FL) / Ren Frac (%) 67.3				
Total Production 21,712 kWh/year				
Primary load 10,950 kWh/year				

The proposed HOMER model allows for the most optimal generation structure with a complete outlook on its economic effect, allowing for a more comprehensive look at such systems' feasibility and economic usefulness. Considering the cost of investment and maintenance, HOMER provides the means to make a precise assessment of the extent to which the installation is beneficial and allows for an accurate outlook about the time it might take for a return on investment to materialize. Table 16 above shows the optimized results of the proposed system. It shows that the system has a COE of Omani Rials of 0.015/kWh or $ 0.039 /kWh, comparing this number with the tariff from the Authority for Public Services Regulation, which is Omani Rials 0.020 or $ 0.052 /kWh [14]. It concludes that the system is feasible as its energy cost is slightly below the tariff the Authority for Public Services Regulation charges for each kWh usage.

3.2 Electrical Energy Assessment

It is necessary to consider the surplus produced power or unmet load demand to optimize and enhance the electrical production and demand system. There isn't any power surplus or untapped power in this instance. Excess electricity is extra electrical energy that cannot be utilized to power a load and must be disposed of (or limited). Surplus power is produced when more energy is produced than is needed (whether from renewable sources or when the generator's low output exceeds the demand). The quantity of electricity the power system cannot deliver is an unmet load. When the supply of power is insufficient to meet demand, it happens. It rarely occurs due to the combined system with the on-grid system, which generates the power required to demand load for an extended period.

- **Annual Energy Cost Saving:** The annual energy-saving cost of the system can be determined from its annual energy production. As indicated in Table 16, the yearly energy production is 21,712 kWh. Then, this annual cost saving can be determined using the current energy tariff in Oman for residential usage of $ 0.052 per kWh. The annual benefit can be calculated as:

  - Annual grid rate = 21,712 kWh × 0.052 $ = $ 1129.02
  - Annual proposed hybrid system rate = 21,712 kWh × $ 0.039 = $ 846.77
  - The annual benefit of the system is 1129.02 – 846.77 = $ 282.43

- **Cash Flow Diagram for the System:** This operational cash flow depicts the capital, replacement, salvage, and operating costs associated with the proposed system design. The discount factor is a ratio based on the discounted rate used to determine the present value of a cash flow that happens in any year of the project's lifetime. A discounted cash flow is a cash flow that has been discounted to zero for years. The results of the cash flow simulation are shown in Figure 16. Each bar in Figure 16 reflects a year's total cash inflow or outflow. The first bar, for year zero, represents the system's capital cost, which is also reflected in the optimization outcomes.

A negative number indicates an outflow, expense for equipment replacements, or operation and maintenance (O&M). Furthermore, Figure 17 illustrates the cash flow for the project for each component in the configuration.

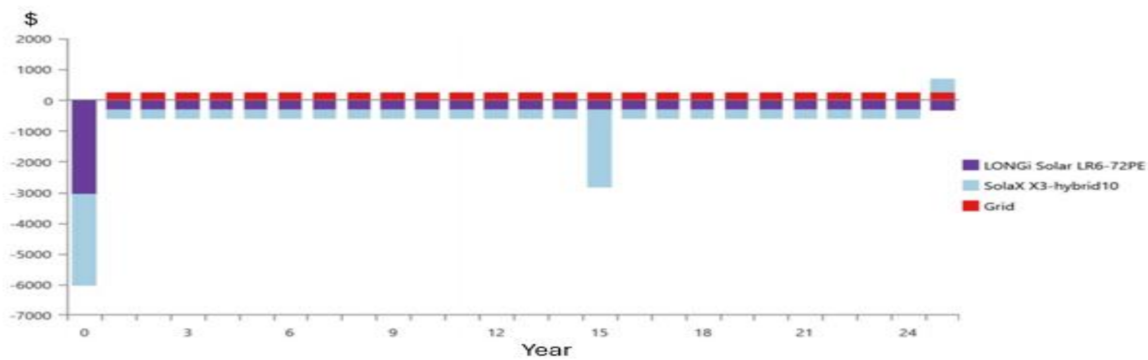

Figure 16: Overall cash flow diagram

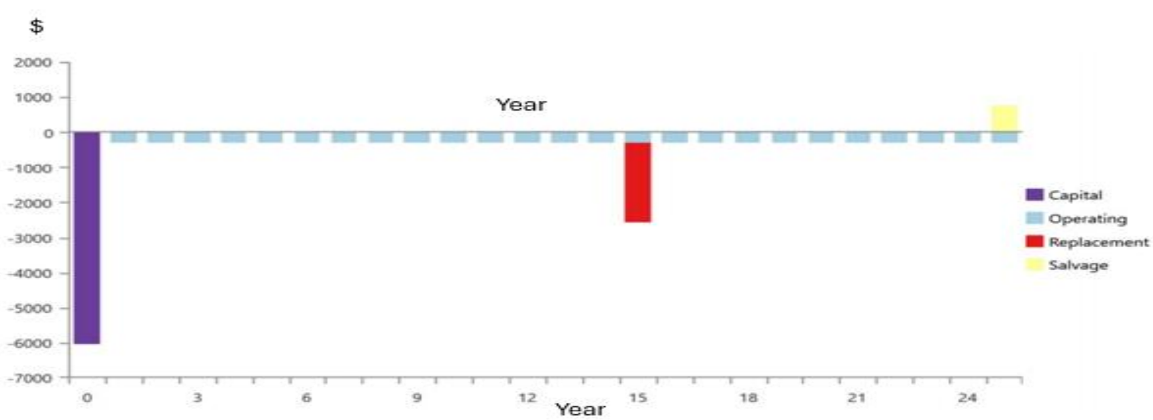

Figure 17: Cash flow for each system component

Figure 16 shows that the cost drastically reduces as the operations go into action. With theoretical replacements being expected occasionally, aside from the initial investment, the operating costs are relatively low and consistent. As mentioned earlier, the converters are the most prone to damage, but in this proposed system, the inverter is selected with 25 years as its lifetime, which is considered, as seen in Figure 17. The most expensive part to generally repair or replace would be the PV parts due to exposure to external environmental conditions. They are expected to require minimal repairs or maintenance unless extreme weather occurs.

3.3 CO2 Emission Analysis

Carbon dioxide CO2 is one of the most significant pollutants among greenhouse gases. It is released when power plants that operate on fossil fuels produce emissions, and these emissions are to blame for environmental problems. Therefore, carbon dioxide levels are reduced by entering renewable energy sources such as PV solar into the network system. Releasing CO2 emissions is now a serious concern worldwide. Further, the proposed project revealed that it reduces the emission of greenhouse gases such as CO2 by a sufficient weight. According to the statistical report issued in 2020 in Oman, generating 1 kWh will release 490 grams of CO2. Thus, using conventional sources to generate 14,756 kWh/year will emit (490 gm x 14,756 kWh/year) about 7,230,440 kg, whereas using and entering PV solar to the grid system will reduce to 4,413.01 kg to generate the same amount of electrical energy as illustrated in Figure 18.

Quantity	Value	Units
Carbon Dioxide	4,413	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	19.1	kg/yr
Nitrogen Oxides	9.36	kg/yr

Figure 18: The projected amount of CO2 emission

4 Conclusion

The design system of a PV solar system-powered station on a small scale was examined in this paper using a residential building in Nizwa, Oman, as a case study. The first task was site survey and selection, then collecting necessary data for the work, including power consumption in the residential building, which is 30 kWh daily base consumption, and having 3.51 kWh as peak load consumed to feed the residential building in the proposed site. Results showed the suggested PV system proved its reasonable economic and environmental feasibility. Although the size research was conducted to supply power to the specific load consumption and in specific building locations, the conclusions and technique may be used on a large scale by modifying the value of load consumption, solar scale, irradiation energy statistics, and other required parameters. Oman has a large amount of radiation during the year. In addition, Oman has renewable energy targets with Oman Vision 2040. Still, there needs to be more solar energy project stations to achieve this target, necessitating the development of a national road map for installation and production station size, regulation, and other considerations. This paper will contribute to assessing solar energy sources for power companies in Nizwa, which has one of the highest GHI potentials in Oman and was chosen to demonstrate PV project size. site.

According to measurement Homer software data, daily radiation at Nizwa is about 6 kWh/m^2/day. The current electricity tariff for residential consumers in Nizwa is about $ 0.052 per kWh, and the grid sell-back is $ 0.066; these are key parameters in determining the feasibility of the PV project. Therefore, using a site-specific parameter, the feasibility study was undertaken using a software package, HOMER. These are some of the most important factors and key parameters to consider while evaluating the viability of the PV project. As a result, a feasibility study was conducted, using this as the site-specific characteristic to assess the viability of the project using a HOMER software program.

The energy system suggested was comprised of a 9 kW PV solar system linked to the grid. The PV system worked perfectly, and it produced 14,756 kilowatt-hours of electricity each year. The proposed hybrid system (PV with grid) produced 21,712 kilowatt-hours of electricity for the whole year. There is the possibility of exporting surplus energy and selling it to the network. The cost of power generated COE was 0.039 per kilowatt-hour in a hybrid system, instead of grid stand-alone, which was $ 0.052 / kWh and 0.059 of PV/Battery/ Grid. Thus, the annual energy-saving cost of the hybrid system was $ 282.43. The hybrid system's total capital cost was $ 6,000.00, and the net present cost was $ 11,102.00. Using and entering the proposed PV solar with the grid system will reduce CO2 emissions from 7,230,440 kg to 4,396.001 kg to generate 4,413.01 kWh/yrs.

The difference in the cost of energy COE and the amount of CO2 levels that will be avoided by introducing the proposed system to the grid are summarized in Table 18 below. As it shows, there is a decrease in energy costs at an acceptable rate and a reduction in CO2 emissions.

Table ١8: The difference in the cost of energy COE and the amount of CO2 levels

	COE- $/kWh			CO2 levels – kg/year		
(City) [Project]	Grid/Stand-Alone (DG)	Hybrid (Grid + PV)	Hybrid (Grid + PV + Battery)	Grid/Stand-Alone (DG)	Hybrid (Grid + PV)	Hybrid (Grid + PV + Battery)
Oman-Nizwa Proposed Work	0.052 (Base)	0.039 ↓	0.059 ↑	7,230,440 (Base)	4,413.01 ↓	3,843.01 ↓

The study established that the suggested small-scale PV solar with On-grid in the proposed residential building in Nizwa City is technically possible and economically viable as a renewable energy source using 9 kW PV combined with the public grid system. In addition, as data in Table ١٧ above, the result of this study in Nizwa shows the proposed system lowered the COE to $ 0.0٣٩ per kilowatt hour compared to the current cost of energy in a standalone grid system.

Recommendation and Extension

To be true, the burgeoning PV panels industry still faces several challenges, such as low efficiency and being directly impacted by dust, temperature, and shading. PV panel manufacturers and researchers should continuously develop testing standards, efficiency, and technology systems. Nonetheless, the Solar projects sector has a bright future. PV projects have the potential to be economically feasible in the future as the public gets more educated and designers and manufacturers improve their technologies in this sector.

In the future, the proposed research work can be extended by adding wind energy systems to reduce production costs further. Using advanced technology battery systems to store solar energy effectively is also recommended. Solar energy system performance can be improved by making the system more innovative, such as solar tracking systems and automatic solar panel dust cleaning systems.

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