Optimal sizing of photovoltaic systems using HOMER for Sohar, Oman

Majid Alabdul Salam*‡, Ahmed Aziz*, Ali H A Alwaeli*, Hussein A Kazem*

*Faculty of Engineering, Sohar University

im12mi@hotmail.com, al-qaysi@live.com, h.kazem@soharuni.edu.om

‡ Corresponding Author; Majid Alabdul Salam, Faculty of Engineering, Sohar University, Sohar, Oman, +968 26720101, im12mi@hotmail.com

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Abstract- This paper discussed the design and analysis of Photovoltaic (PV) system to supply lighting load for Renewable Energy Lab. The procedure of this paper was the measuring and collection of the basic meteorological data of solar radiation for Sohar-Oman, and then standalone system optimization simulation model was developed using the renewable energy software HOMER. Simulation model has been used to find out the best result optimization based on energy efficient system for the specific load. The optimization found that the PV array rated capacity is 0.7 kW, which produces 1,316 kWh/yr. The results indicate that the solar energy utilization is an attractive option with initial cost, net present cost of the system, and energy cost are 3,425 US$, 6,233 US$, and 0.561 US$/kWh, respectively, in comparison with diesel generator operating cost 0.558 US$/kWh. We conclude that using the PV system for different applications in Oman is justified on economic and technical grounds.

Keywords- Photovoltaic, Solar System Design, Optimization, HOMER.

1. Introduction

In view of apparent unlimited potential energy solar energy came as the most promising of the renewable energy sources. The sun radiates its energy at the rate of about 3.8 × 1023 kW per second [1]. Most of this energy is transmitted radially as electromagnetic radiation, which comes to about; 1.4 kW/m2 at the boundary of the atmosphere. After traversing the atmosphere, a square meter of the earth's surface can receive as much as 1 kW of solar power, averaging to about 0.5 over all hours of daylight. Although solar radiation intensity appears rather weaken when compared with the volumetric concentration of energy in fossil fuel. In solar PV applications, the solar radiation is converted directly into electricity. The most common method of doing this is by the use of silicon solar cells. The power generating unit is the solar module which consists of several solar cells electrically linked together on a base plate. The major components of a PV system include the arrays which consist of the PV conversion devices, their interconnections and support, power conditioning equipment that convert the DC to AC and provides regulated outputs of voltage and current; controller, which automatically manages the operation of the total system; as well as the optional storage for standalone (non-grid) systems [1]-[3].

The cost of fossil fuel based electricity generation in the long term may increase and the production costs of renewable energy technologies decrease due to construction optimization and increased efficiency. The issue is finding an appropriate starting point and development scenario for the use of renewable energy in Oman that may lead to the zero carbon scenarios. Crude oil is still the major source of Oman’s economy. Its share along with natural gas stands at around 78.4% of the Government’s gross revenue [4].

Peak electricity demand in Oman has increase from 2,773 MW in 2007 to 4,634 MW in 2013 and expected to increase to 5691 MW in 2014. The annual growth rate is approximately 17.8% and it is high. Peak electricity demand is envisaged to continue increasing due to the accelerated growth in Oman. These projections are based in part on current usage of nonrenewable and renewable energy sources. Hence, to reduce the gap between production and consumption, additional usage of energy sources other than fossil fuels and gas are required. In this regard, renewable energy sources (RES) appear to be the one of the most efficient and successful solutions [5]. Solar energy in Oman found to be among the highest globally. The location of Oman is in the Middle East, on the eastern edge of the Arabian Peninsula. The longitude and latitude of Oman is (57 00E, 21 00N). It is generally very hot, with temperatures reaching 48 ◦C in the hot season, from May to September. In addition, the climate of Oman remains dry (no rainfall) and extremely hot. Therefore it is found that solar PV technology is suitable producing electricity for use in northern parts of Oman and in desert areas [3]-[5].The average global horizontal annual solar resource is 5.936-6.879 kWh/m2/day [6, 7].

The efficiency of PV cells is influenced by high air temperature and dust contamination. It is estimated that the environmental conditions in Oman would reduce the efficiency of PV cells by approximately 10 % compared to standard condition [8]. The technical potential for electricity generation by grid connected PV systems is determined by the area available for installation of PV cells (e.g. on buildings, parking areas etc.).

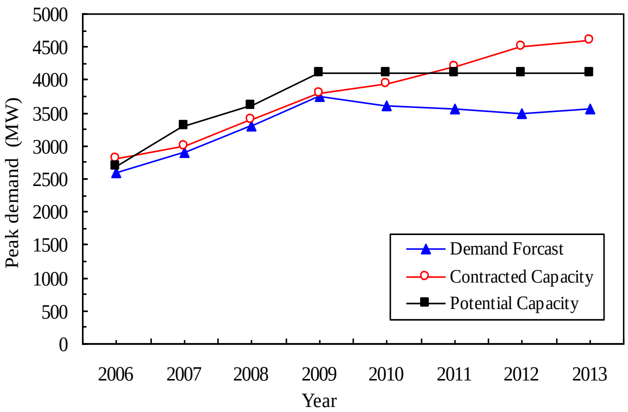

Fig. 1. Projection of the peak electricity demand in Oman till 2013 [5].

HOMER, the micro power optimization software developed by Mistaya Engineering, Canada for the National Renewable Energy Laboratory (NREL) USA, used in this analysis simplifies the task of evaluating designs of both off-grid and grid-connected power systems for a variety of applications. In designing a power system, many decisions about the configuration of the system are to be made: components to include in the system design, size of each component to use etc. The large number of technology options and the variation in technology costs and availability of energy resources make these decisions difficult. HOMER's optimization and sensitivity analysis algorithms make it easier to evaluate the many possible system configurations [2].

HOMER simulates the operation of a system by making energy balance calculations and displays a list of configurations, sorted by net present cost that can be used to compare system design. Many references have studied the optimum design of PV system using HOMER software [9]-[13].

Reference [9]; addresses the need for PV solar system to power a health clinic in the rural areas in southern Iraq. The authors used HOMER software computer model to determine the most economic system. They proposed system with a daily load of 31.6 kWh which is composed of 6-kW PV modules, 80 batteries (225 Ah and 6 V), and a 3-kW inverter. The total initial cost, net present cost, and cost of electricity produced from the system are 50,700 US$, 60,375 US$, and 0.238 US$/kW h, respectively. The analysis shows that the price of electricity produced from the diesel generator is four times greater than that produced from the PV system, which highlights the benefit of using this system in remote areas. The analysis also shows that using this small PV system instead of a diesel generator can prevent the release of 14,927 kg/year of CO_2, 36.8 kg/year of CO, 329 kg/year of NOx, 4.08 kg/year of HC, 30 kg/year of SO_2, and 278 kg/year of suspended particles.

Reference [10]; the authors proposed an optimization solution of a hybrid system of renewable energy by using the Homer software for remote areas in Tunisia. The Hybrid systems involve combination of different energy sources like wind/battery, PV/battery, wind/PV/battery, wind/PV /diesel/battery. The climatic data are specific for the area of Hawaria in Tunisia. The optimal configuration of the hybrid system wind/PV/diesel/battery intended for reliable load supply and also considered the meteorological data changes is deduced from two optimal configurations selected: (wind/PV/battery) and (diesel/battery). For the wind/PV/ battery the optimal configuration is composed by 8 kW panel PV, 2 wind turbine, 118 batteries and 12 kW power converters. The initial cost and the operation cost 165.450 US$, 2.102 US$/yr respectively. The total net present cost 189.559 US$ and the cost energy produced 0.540 US$/kWh. For the diesel / battery the optimal configuration is composed by 5 kW diesel generator, 18 batteries and 2 kW power converters. The initial cost and the operation cost 11.934 US$, 10.707 US$/yr, respectively. The total net present cost 134.747 US$, the cost energy produced 0.382 US$/KWh and the diesel 11.269 L. For the wind/PV/diesel generator/battery with load of 85 kWh/d the optimal configuration is composed by 8 kW panel PV, 2 wind turbine, 118 batteries, 5 kW diesel generators and 12 kW power converters. The authors proves that the combination of a diesel generator, as buck-up source, with the hybrid wind/PV/battery system is the best solution to guarantee the reliable supply without interruption of the load under the climatic data change. The optimal sizing of the hybrid wind/PV/diesel/battery system is deduced from the two optimal configurations chosen: (wind/PV/battery) and (diesel/battery).

Reference [11]; discussed the efficient system of sustainable renewable energy for domestic used and its total cost in Khartoum in Sudan. The author's method was the collection of the basic data of solar radiation, wind speed and other required input data, and then the authors used HOMER software to develop the hybrid optimization simulation. The proposed load is 54 kWh/d, and 5.3 kW as a peak. The cost of the PV module including installation has been considerate as 220 SP/W for Sudan. The cost of turbine with tower and installation has been considered as 96000 SP/turbine. For load higher than 1 kW, turbine from southwest wind power (model: W175, capacity, 3 kW) has been considered at the cost of 200000 SP/turbine with tower and installation. The operation and maintenance cost has been taken as 500 SP/year. In addition 800 kW converter and 3500 batteries were considered and the total net present cost 19.1 US$. The authors found that it is better to use wind/PV combination system for 50 homes instead of single home system. In addition if the turbine cost decreases in Khartoum the overall cost of energy would be low. The simulation results display that utilizing renewable generators, such as wind generator and PV reduces the operating costs using a third class of housing at Khartoum state.

Reference [12]; used HOMER software for optimization to find the best cost benefit of hybrid -solar power generation relative to use cost in Nigeria. The cost benefit analysis of a wind/solar hybrid system was done using HOMER software and comparison was also made with utility supply. Central grid power is the least expensive option but may not be available to most rural households far from the grid. Hence it is necessary to supply these areas from isolated power sources. The proposed system used (0.05 – 0.4 kW) PV panel with (0.4 kW DC) FD series wind turbine, (0.1 – 1.5 kW) converter, and (200 Ah / 12 V, bank size: 1-8 batteries, vision 6 FM200D) battery. The authors result obtained from the optimization gave the initial capital cost as 3,455 US$ while operating cost is 69 US$/year. Total net present cost (NPC) is 4251 US$ and the cost of energy (CoE) is 1.74 US$/kWh. The authors found that, the hybrid system have a pay-back period of about thirty-three years and at current costs.

Reference[13]; designed a hybrid power generation system suitable for remote area application by using HOMER software, having a primary load of 3 kWh/d and a 307 peak, it is being supplied by a Micro-hydro model, wind turbine models, PV array models, a diesel generator and batteries. The Micro-hydro model is designed to produce a 100 kW of capacity, having a capital cost of 300,000 US$ and a replacement price of 300,000 US$, the operating and maintenance (O&M) cost is 2% of capital costs of 6,000 US$. There are 18 WES wind turbine, having a capital cost of 11,000 US$, a replacement cost of 10,000 US$, and O&M of 110 US$ per year. There are 200 PV model in the system, with a capacity of 200 kW (1 kW for each array). The capital cost and the replacement cost are 5,600 US$ and 5,000 US$, respectively. The O&M cost is 10 US$/year. There is one battery of 6 V, and a capacity of 6.94 kWh. The capital cost of the battery is 700 US$, the replacement cost is 600 US$, the O&M cost is 0.1 US$/year. There is only one diesel generator with a capacity of 70 kW, a capital cost of 18,000 US$, a replacement cost of 18,000 US$, an O&M cost of 0.15 US$/year. Also, a converter (inverter/rectifier) that has a capacity of 1 kW, a capital cost of 140 US$, a replacement cost of 126 US$, an O&M cost of 0.15 US$/year. The author illustrates the importance of equalizing between economy, environment and energy, through determining the optimum hybrid configuration. Also, the cost of energy in the purposed scheme is comparably higher than the conventional energy sources, but with more efficiency and less environmental side effects.

This paper describes the designing and implementation process of PV system in Sohar-Oman using HOMER software. The electrical demands are listed and system design optimization is done based on hourly data measured in Sohar.

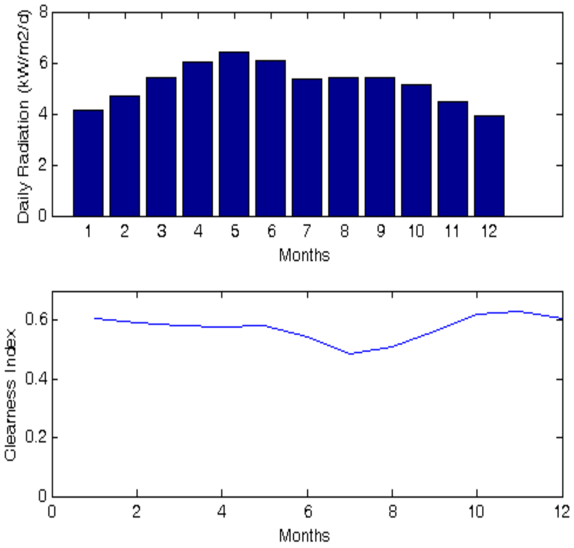

Fig. 2. Solar radiation profile

2. Description of the Proposed System

PV modules generate DC electricity which converted to AC using inverter to supply the AC load. This electricity can be used at night by employing a storage mechanism such as a battery. Batteries used for this purpose have a large storage capacity. As we know that PV system will produce DC current in order to provide AC current we use inverter. The systems contains, PV modules, inverter, batteries, circuit breakers and special cables in order to supply efficient power for the specified load.

2.1. PV Array

In a solar PV, a semiconductor absorbs the energy of sunlight in the form of photons, which are then converted to a voltage via the movement of electrons. PV cells added together to produce module. Modules put together to form array. The suggested PV modules to be used in the system simulation are 12 V, 140 W (at 1000 W/m^2, and 25 ^{o}C). These modules are connected to produce array with 24 V. Estimated capital and replacement cost of PV is 7.0 US$/W. The lifetime is assumed to be 25 years. 90% derating factor was applied to the electric production from each PV panel. The panels were modeled as fixed and tilted south at an angle equal to the latitude of the site. Capacities of different PV panels (0, 0.28, 0.42, 0.56, 0.70, 0.84, 0.98, 1.12, 1.26, 1.40, 1.54 and 1.68 kW) were considered in the analysis.

2.2. Batteries

As the system considered working 24 hours, battery and controller were also formed as a main part of the system. Throughout battery life time HOMER assumes that the properties remain constant and not effected by external factors such as temperature. The chosen battery has a 6 V, 360 Ah capacities. The battery price estimated to be 200 US$. Its life time is considered to be 1,075 kWh of throughput per battery. Different number of batteries considered in this analysis (0, 1, 2, 3, and 4).

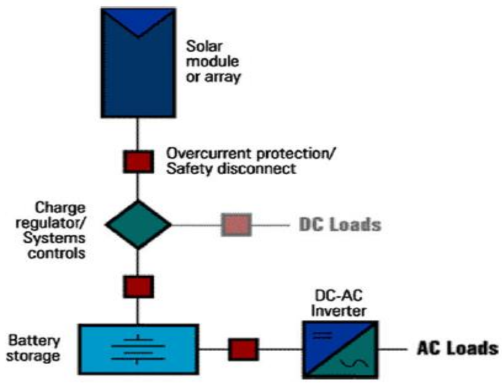

Fig. 3. Block diagram of PV system [3]

2.3. Inverter

An inverter is a circuit converts DC power to AC. Its efficiency is assumed to be 94.1 % for all sizes considered. The estimated price of an inverter is 0.9 US$/W, and its lifetime is up to 15 years. Inverters of various sizes (0.25, 0.50, 0.75, 1.00, 1.25, and 1.5 kW) were considered in the analysis.

The proposed loads are energy conservative load in comparison with the load type used now days in Oman. It is representing the average daily electricity that is use by household also; we tried to define the amount of energy that the PV system must generate daily. The hourly load profile is used to light the renewable energy lab at Sohar University is shown in figure 4. The load represents 10 LED lamps (10 W each). A small base load of 0.04 kW occurs from 5 PM until 6 AM. This load is for outside lighting and some inside lighting, where the majority of the load is occurs during the day from 7 AM to 4 PM. The average daily load demand is 1.56 kWh/day, with a peak power equals to 189 W.

3. Optimal Size of the Proposed System Using HOMER

As mentioned before the system consists of; PV modules, batteries, charge controller, inverter, and the necessary wiring and safety devices. The system feasibility analysis was performed using the HOMER software. HOMER is a computer model that simplifies the task of evaluating design options for both off-grid and grid-connected power systems for remote, stand-alone, and distributed-generation (DG) applications.

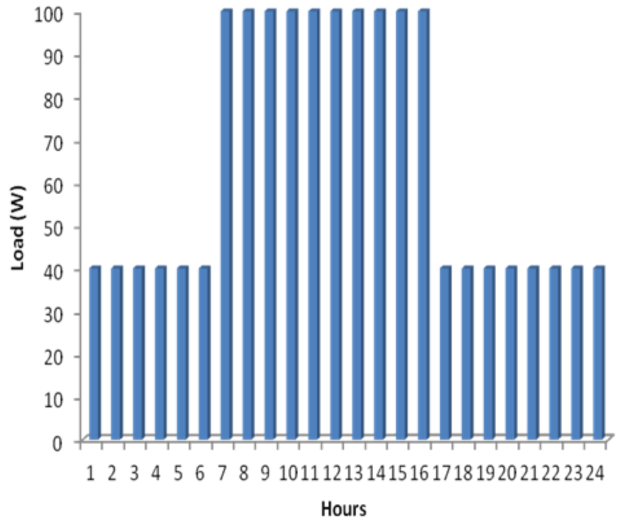

Fig. 4. Hourly load profile

HOMER's optimization and sensitivity analysis algorithms allow one to evaluate the economic and technical feasibility of a large number of technology options and to account for variation in technology costs and energy resource availability. HOMER models both conventional and renewable-energy technologies [3]. HOMER models a power system's physical behavior and its life-cycle cost, which is the total cost of installing and operating the system over its life span. HOMER allows the modeler to compare many different design options based on their technical and economic merits. It also assists in understanding and quantifying the effects of uncertainty or changes in the inputs. Figure 5 shows the schematic diagram considered in the optimization. The equipment's considered are PV, converter, battery bank and loading system.

3.1. PV Array Data

For the PV array the capital and replacement costs were specified with 1120 US$ and 840 US$, respectively. Little maintenance cost was considered for the panels around 20 US$/yr. A derating factor of 90% and 25 years lifetime was considered as shown in figure 6.

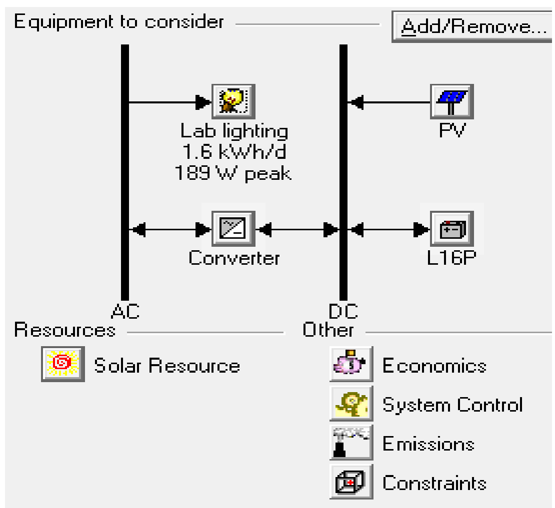

Fig. 5. Schematic diagram of the proposed system.

3.2. Battery Data

The battery chosen is the 6FM200D. It has a nominal voltage of 6 Volts and nominal capacity of 360 Ah (2.16 kWh). Four batteries were considered by HOMER in the simulation shown in Figure 7.

3.3. Inverter Data

The inverter efficiency was assumed to be 94.1% for all the size considered. The size considered is 0.25 kW. The converter input is shown in Figure 8.

3.4. Load Data

A typical lighting load was considered. The consumption includes 10 LED- bulb points as shown in Figure 9.

The size of the components under consideration, the acquisition cost, replacement cost, operation and maintenance cost and the expected lifetime as input into the HOMER software is depicted in Table (1).

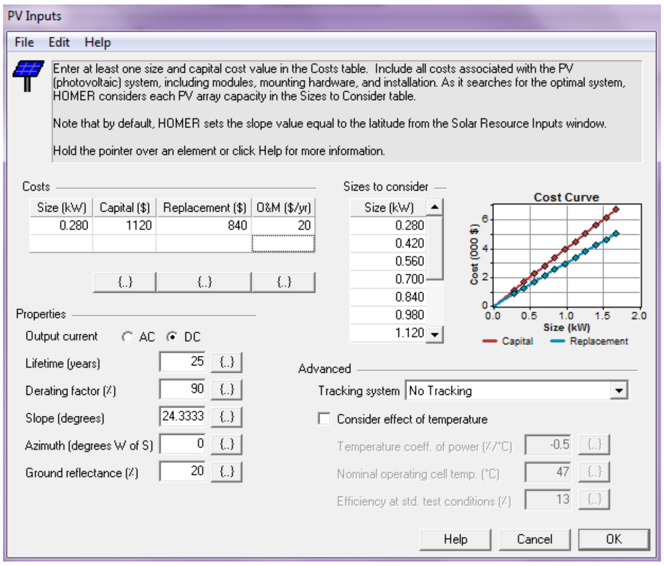

Fig. 6. Photovoltaic solar input

Figure 10 shows the power generation shares in the proposed system. The PV array rated capacity is 0.7 kW and it is produces 1,316 kWh/yr. Also, it is mean output is 3.6 kWh/d and capacity factor is 21.5. As for the battery, it is used in almost 25% of the year time and the annual throughput is 248 kWh/yr. The energy demand of the proposed system is 569 kWh/yr. The initial cost, net present cost of the system, and energy cost are 3,425 US$, 6,233 US$, and 0.561 US$/kWh, respectively.

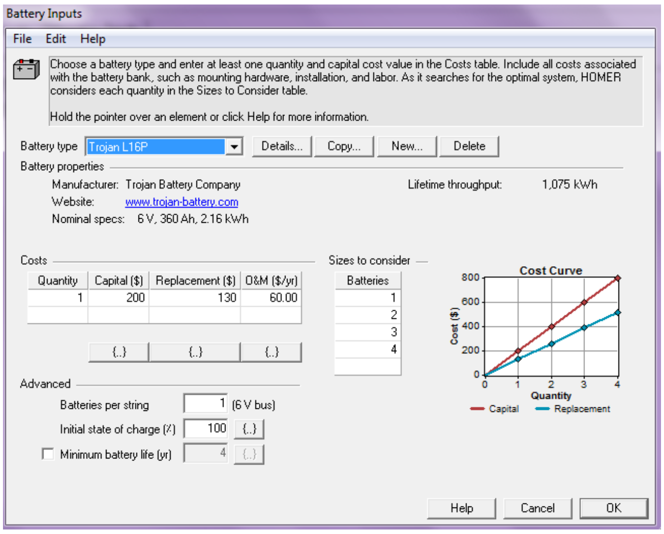

Fig. 7. Storage batteries input

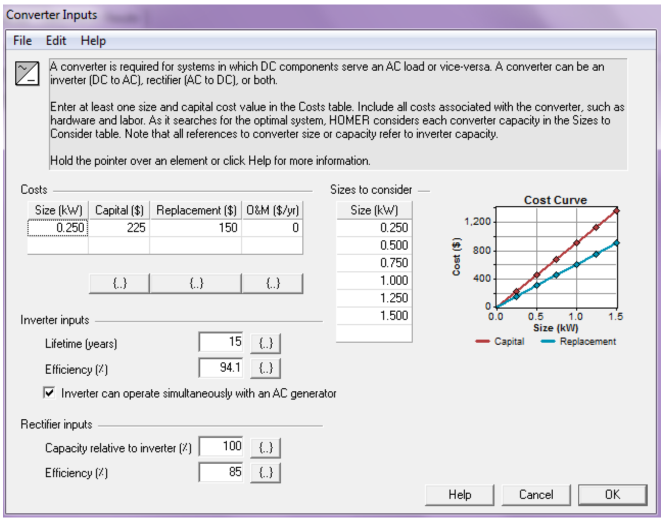

Fig. 8. Converter input

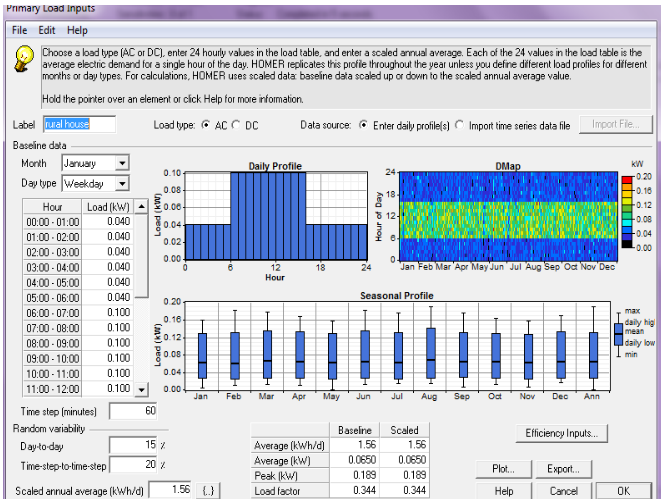

Fig. 9. Load input

Table 1. System Components

	PV	Bat	Inv
Life time	25	5	15
Capital cost US$	2,800	400	225
Replacement US$	0	403	111
O&M US$	0	2,343	0

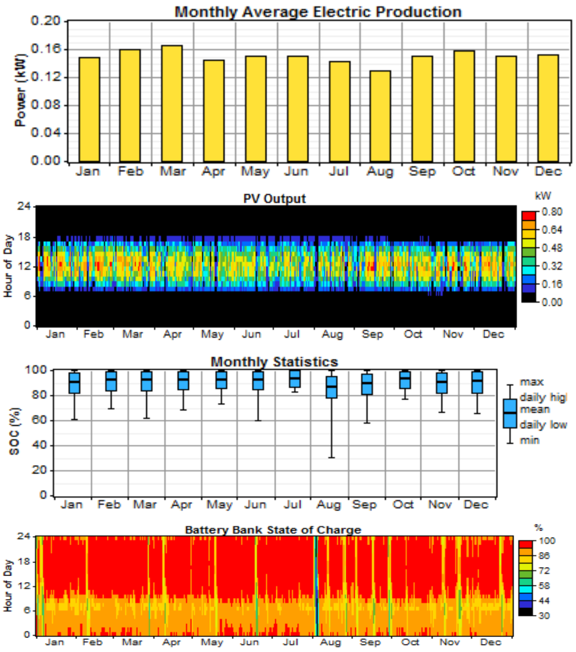

Fig. 10. Power generation share of the proposed system

The current energy cost of diesel engine system 0.5581 US$/kWh [14, 15] is close to the proposed system, which make it a good option for different applications in Oman. This is due to poor efficiency of diesel engine and short life time. Also, emission of greenhouse gases from the fuel of equivalent conventional system is significant. By adapting PV technology, the emission of all these harmful gases can be substantially reduced.

4. Conclusion

A proposed PV system has been designed and optimesed using HOMER software computer model to supply lighting load for renewable energy lab in Sohar University. All the optimization systems are ranked according to net present cost, and all other economic outputs are calculated for the purpose of powering the lab and finding the best net present cost. The result obtained from the optimization gives the initial capital cost as 13.500 US$ while operating cost is 817 US$/year. Total net present cost (NPC) is 23.939 US$ and the cost of energy (CoE) is 1.354 US$/kWh.

Results shows that the numbers of batteries used to obtain the best total Net Percent Cost (NPC) are four batteries when the size of the used converter is 1 kW. The initial capital cost depends on the size of the PV panel, the number of the batteries used and the size of the converter because the system is a fixed PV panel. The performance of the PV system depends on the range of daily radiation (kWh/m^2/d) and the clearness index for each month during the year.

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