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DEVELOPMENT OF A PV SYSTEM AT ICT LABORATORY IN OMAN – SUMMARY OF TECHNOLOGICAL DEVELOPMENT

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ABSTRACT
The social and financial expansion of a country significantly depends on the role of the Energy. Solar energy producing power as clean energy can be used as alternative resource of fossil fuel, which has limited availability. The advancement in technology able to generate lower cost power used for daily electricity demand in a laboratory / building. This research focus on recent development in solar PV module and to compute the cost of a solar module for a laboratory in engineering department of ICT, Ibra, North Sharqiyah Region in Sultanate of Oman. The cost computation has been done on the availability of the solar radiation data in North Sharqiyah region of Oman to calculate and assess the working principle of PV system. This research has main objective to compute optimal size of a solar PV model suitable to Materials Laboratory based on the solar radiation data available.

Keywords: Solar Energy, Solar Radiation, PV Module.

1. INTRODUCTION

Al Sharqiyah region is located towards the north-east side Oman, facing towards east of the Arabian Sea and extend towards south to reach Al-Wahiba sand and facing west of Al Dakhilyah. Sharqiyah region has total population of Omanis about 264,090 Omanis and expatriates 48,618 according to 2003 Census. The Sharqiyah region divided into two regions, South Al Sharqiyah region includes 5 willayats and North Al Sharqiaya region includes 6 wilaya as Ibra, Al Mudaibi, Al Qabil, Dimma & At Tayyin, and Wadi Bani Khalid. The population in Ibra is about 65,000 people and considered as the second major city in the Al Sharqiyah region of Oman. Ibra is becoming one of the big educational hub in this region. Ibra is surrounded by Mountains on each side. The climate of Ibra from the month of November to March is low around 10^0 C in the month of December. During summer season the hot and dry climate available every year and temperature can reach up to 50^0C in July. The average annual temperature in Ibra is around 28^0 C. Ibra College of Technology, Ibra run under Ministry of Manpower funded by the government to provide education to full time Omani students in the north of Al-Sharqiyah region of the Sultanate of Oman. After graduation of students participate in the social and economic development of the nation. The Sultanate of Oman located amid latitude 16^0 and 28^0 N and longitudes 52^0 and 60^0 E. The weather of Oman is normally arid that can differ from one region to another.

The energy demand in the world by 2050 will become two or three times due to fast increasing in population and also economies of developing nations are expanding. Energy plays significant role for the development of a society as well as financial growth of a nation. The planes, power plants, trains, and automobiles in major countries operated by fossil fuels from 200 years, which is prime cause to change the climate and global warming by emissions of carbon and greenhouse gas to increate temperature of environment. The consequence has discussed as obtainability of fossil fuel, oil era and the keenness for the end of the fossil fuel era due to environmental impacts and more use of renewable resources and practice (Foster et al. 2010). Renewable energy is the alternative resource of energy as fossil fuels producing more co_2 emissions. In renewable solar energy is most significant due to easy availability of sunshine and less operating cost. Globally from 20 years many research centers are working for the improvement of solar technology to reduce the initial cost of solar energy also gets its advantageous impacts on the ecological, and political subjects of the world (Sayigh, 2001). Solar energy is the most significant source of energy among renewable energy resources, which can be considered as the alternative source of energy, it has two working principles to generate power, one as photovoltaic system and other as solar thermal system (IEA, 2009). The researchers did analysis on the earned of carbon credits by installing solar PV system and concluded that it is also cost effective than the application of conventional generation of power. Another benefit is in terms of carbon emission controlled by renewable energy compare to conventional source of energy (Prabhakant and Tiwari, 2009).

The semiconductor materials are used to make solar cells to generate electricity. As sunlight falls on the solar cells, photons are responsible to supply the required energy to break the valence bonds between electrons, so that electrons freely move in the conduction band and conduct electricity through the material. Photovoltaic (PV) system using semiconductor materials when exposes to sunlight, it absorbs photons and free the electrons from the material and producing direct current (DC), which can be measured in watts (W) or kilowatts (kW). The directly produced energy directly used in remotely placed regions, which are far away from the nearby grid. PV system placed remotely, facilitate people with lights, fans without using diesel engine, even a water pump can run easily to supply the water in remotely placed villages. Electricity can be supplied to transmitter stations through remotely placed PV system. In PV system, Module is formed by encapsulation of solar cells as one unit by interconnect the cells. The DC current generated by PV modules using inverter converted to AC current. Presently, the scope of solar energy in Oman has limited scope like street lighting in cities, for telecommunication station remotely situated, etc. (Al-Badi et al. 2009). There is initially high investment required to installed renewable energy resource, but due to technological advancement in semiconductor materials will reduce the initial installation cost of photovoltaic system, so a lower cost PV system can be used in remote areas.

Oman has main dependency on the resource of fossil fuels like oil and natural gas to generate power, due to its significant reserves of petroleum products. But oil reserves in Oman is limited in compare to other Middle East countries so government thinking to opt other source of energy which has less impacts on environment also. Fossil energy resources like coal, gas, etc are producing co_2 and S-emission causes to increase the temperature of environment as well as polluting the environment. Researcher discussed the use of renewable energy resource versus fossil resource to generate the green and clean energy (Foster et al. 2010).

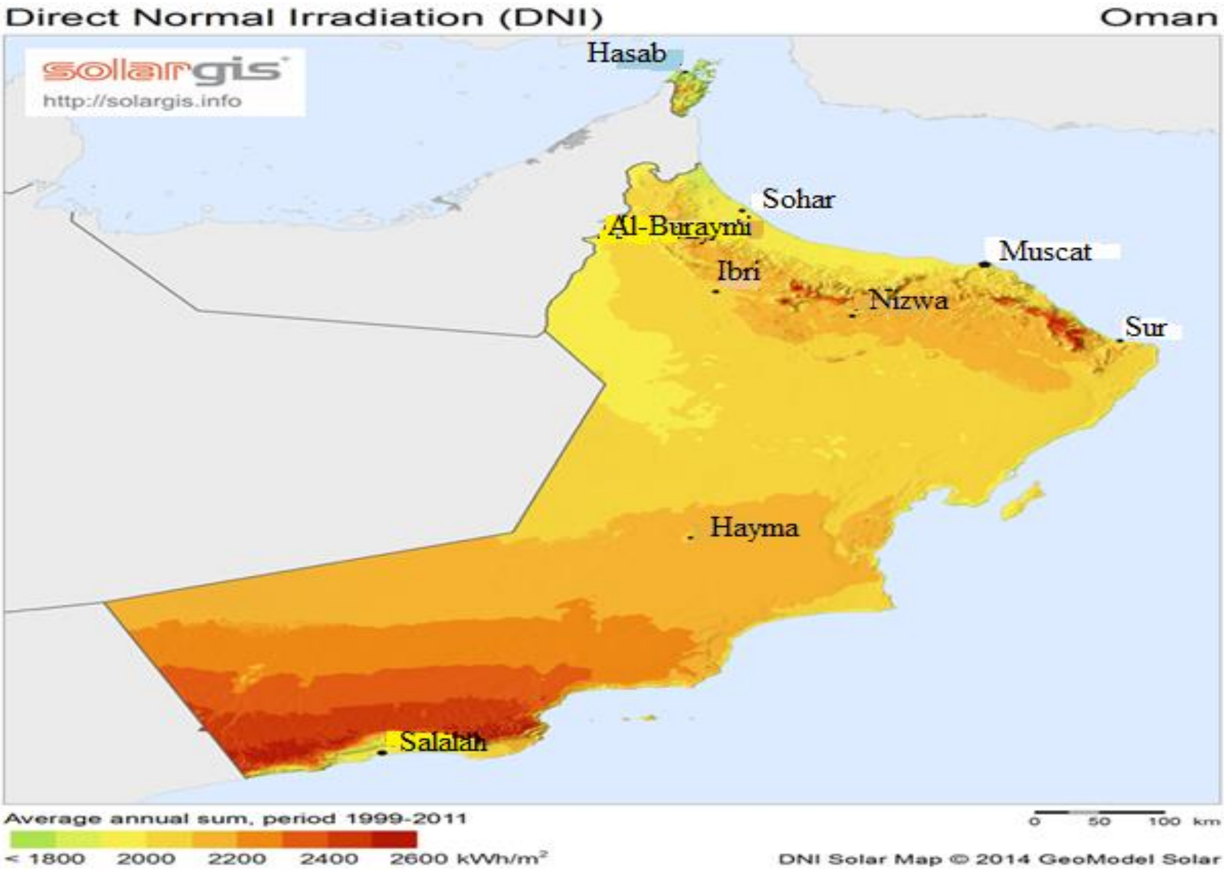

Fig. 1 Solar radiation on Sultanate of Oman (sources Solargis)

This research recognizes the significance of solar PV system technologies and its suitability in Oman and also recent developments in solar cell materials. The objective of this research is to consider PV System as alternative energy resource for laboratories at ICT, Ibra, Oman. The PV module used for energy generation in this research has been also observed for the utilization of energy and cost computation of the solar panels placed in in lab. The paper is organized as follows: firstly, paper will look for the opportunities of demand management in a lab. Then, paper focus on the opportunity of the more usable tariff structure introduction. After this, paper considered the technologies currently accessible in the market and lastly, paper analyze and compare the different technologies, based on some selected characteristics. Figure 1 shows the high solar radiation data available in Oman.

2. PHOTOVOLTAIC (PV) SYSTEM BACKGROUND

In Oman context, a study recognize the source of renewable energy as solar and wind, which can be used in future to generate significant percentage of power production. This research has taken solar energy or photovoltaic (PV) energy as the most significant source to generate electricity in remote area or as a source of clean energy. The solar cells are the primary elements made of semi conducting materials of a PV system, which absorb the incident sunlight and gives this heat energy to freely moving electrons by photons to produce electricity. The interconnection of solar cells are made to each other and encapsulated in one unit called module, which further fixed in photovoltaic arrays of some meters in length. The more sunlight focuses on the PV array plate, the more freely electrons moving freely to generate electricity. So, the solar panels are installed in south facing direction for maximum fall of sun light on it or mounted on tracking device to capture more sun light over the day. According to the requirements of electricity in a house hold or in a Laboratory, the number of PV arrays computed, for example, generally a house / Laboratory required 20-40 PV arrays to generate power to connected electrical appliances used. If the requirement of power for a house / Laboratory is more than hundreds of photovoltaic arrays can be connected to each other to form as a single unit of photovoltaic system. Figure 2 shows the cell, module and array in PV system.

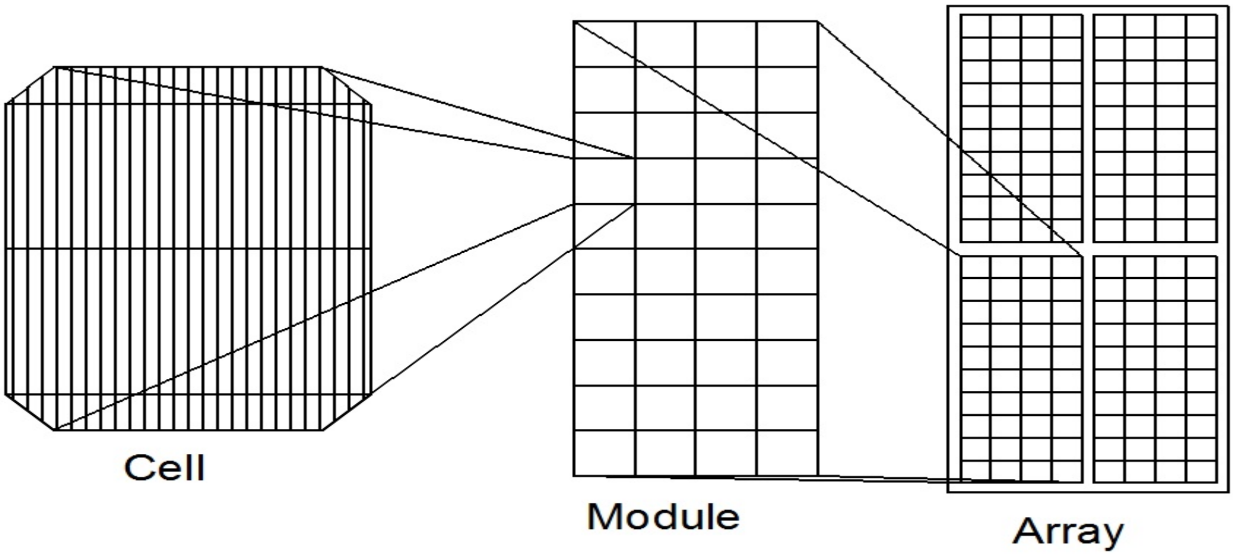

Fig. 2 Photovoltaic cells, modules and arrays

A lens is placed in concentrating collectors to increase the performance of a solar cells by focusing the more sunlight onto the cells to produce more electricity. When sun's energy concentrates of silicon cells than some of it is converted to electricity where as other part absorbed by the silicon materials of cells or reflected. It is supposed that the efficiency of a solar cell is around 15% of efficiency, when more arrays are used then its efficiency can enhance but it also increases the cost of a solar cell. To improve the performance, reliability and efficiency of a solar cell and decrease initial cost, many researchers are continuously working on it. The efficiency of 1st solar cell erected in 1950s was around 4% (Go solar® company, 2005). New materials developed with low cost causes to be coming down of the price of PV system, so increasing the demand of it. (Sustainable power for the world, 2003). Ramavarma explained in 2009 about the more potential of Arab countries to generate solar power around 630,000,000 megawatts and wind power as 75,000 megawatts. (Al-Badi et al. 2009) have identified the obstacles for the application of renewable energy in Oman by assessing the accessibility of resources. They have pointed out about future energy in Oman can include more solar and wind resource if the higher authority gives their consent to use the resource of renewable energy. (Al-Yahyai et al. 2010) discussed about the tremendous potential of wind energy in Oman coastal as well as mountain area especially during summer by comparing the existing data available at weather stations. In context of Oman, present status and the challenges faced to adopt PV system and the getting the new opportunities has been discussed based on availability of global radiation data to optimal design and working principle of solar PV system for a remotely placed village to provide water supply system as well as for house appliances (Sujit, 2013). The suitability of a water pumping system run by solar system compared with diesel engine remotely placed in Northern Badia of Jordan has been discussed by studying some variables as investment need and the cost of fuel (Mohammad, 2012). The research has been focused on rooftop PV System to get optimal sizing of PV system, data has been collected from installed PV system in Austria from 2008 to 2013. It has been observed that initial cost of investment for a minimum of 5 kW size decreasing by 2.2% lower than the same amount already installed (Michael et al., 2017).

The size and capacity of the solar panel array used in a PV system can vary from place to place depending on the requirement of power and availability of sunshine energy. That's why the cost and size of a required photovoltaic system differs from countries to countries. Commonly, the solar PV system cost differs from the commercial use of capacity (700 kW) of \$5.6/W whereas for residential application (2 kW) of \$5.5/W. The solar PV system output depends on the factors like, air temperature, orientation, total irradiance, spectral irradiance, wind speed, soiling and various system related losses. The weathered proof solar panels of a PV system appropriate for all weather can be placed on a roof having no shades so that to absorb the maximum energy from sunlight. The photovoltaic system efficiency can be find as (Sujit, 2013):

$$\eta = \frac{P_{\max}}{E_{tot} \cdot A} \times 100 \text{ ----------------- (1)}$$

where, P_{max} is peak PV power, A is device area and E_{tot} is total incidence irradiance.

2.1 Peak Power Ratings

Pacific Gas and Electric Company and the Photovoltaic for Utility-Scale Applications (PVUSA) has done the regression analysis to measure the PV module or system power (P) can be determined as:

$$P = P_{\max}(E_{tot} \cdot T_a \cdot S) \quad \text{-----------------} \; (2)$$

where, T_a is the temperature and S is the wind speed. Figure 3 has been taken from the thesis submitted by Ibrahim A Al-Busaidi in 2005.

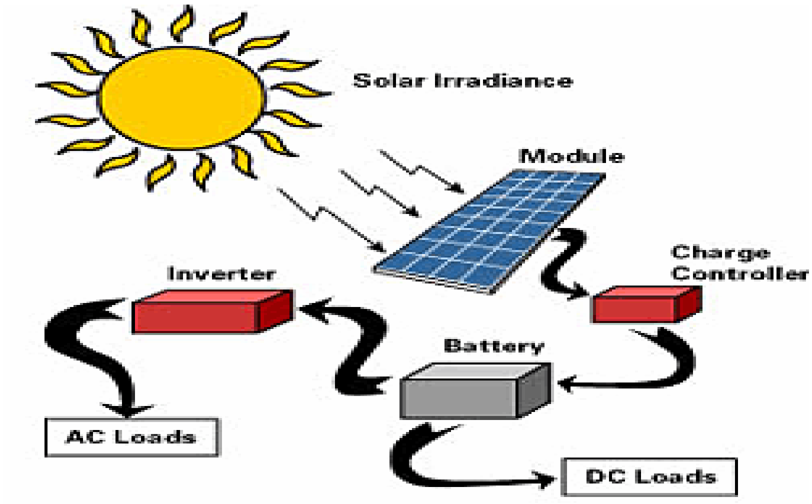

Fig. 3 Photovoltaic system arrangement

2.2 Working Principle of PV System

Silicon semiconductor materials in the solar cells are constructed by two or more layers as P-N structure, one layer consider as a positive charge (P type) and other as a negative charge (N type). When the sunlight strikes the solar cell, the atoms of semiconductor material absorbed some of the photons from light and excite some of the electrons in the semiconductor materials, finally, electrons move to the negative layer of cell to positive layer as connecting wire connects both layer. As a result electric current flow through the device connected externally. The performance and efficacy of cells can be improved by incorporating some solar PV cells. Module is an assembly of PV Cells by wired all cells and sealed as one unit. The module voltage can be doubled by keeping the current constant when two modules wired in series. Similarly, module current can be doubled while keeping voltage constant when two modules wired in parallel. Hence, modules are wired in series and parallel depending on the requirement of power called PV array. Figure 4 represents the connection of two modules for getting desired output.

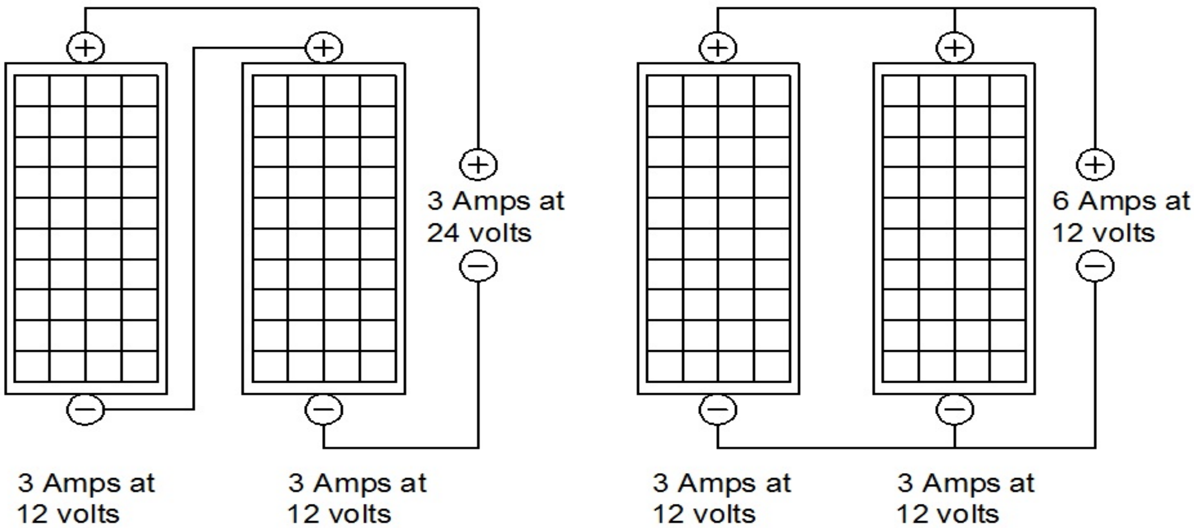

Fig. 4 Module connected in series (shown left) and parallel (right)

In Oman due to easily and cheap availability of prime fuel as oil and natural gases has been taken as main source to generate electricity that's why higher authority has less attention to focus on solar energy, which is available in high quantity every day. On the other hand, remotely placed some areas are still practicing diesel engine for water pumping system, need to be changed by photovoltaic system, which are more reliable and very less impact on the surroundings. A case study has been considered to design and compute cost of a optimal photovoltaic system installed for a remote house situated in Bihar, India. The cost of a suitable PV model computed based on the investigation of energy requirement of a house in a day (Sujit 2015). Researcher proposed a suitable solar PV system / Wind energy system that would deliver sufficient power for a settlement in rural areas in Iraq (Salwan and Sopian, 2010).

3. POWER SCENARIO CONTEXT OF OMAN

According to Power & Desalination Projects, Oman's currently connected and contracted electricity capacity is 4179 MW. Present scenario, around 7.5% power shortage is there To overcome this shortage, new plant is coming in Sur, Barka 3, Salalah, and Sohar 2 is 3784 MW by 2014. The total capacity of 6.6 MW for renewable energy are also going to installed as 6 pilot projects 6 MW by investing plan of 8.1 million OMR at different suitable locations in Oman. Additionally, after approval from Rural Areas Electricity Company (RAEC) 6 projects of size 11 GWh need to be installed to substitute the energy produced by diesel engine, which can save diesel quantity per year as 3.1 million liters and evade the emission of CO_2 per year as 8298 metric tons (Al-Busaidi, 2013). According to annual report prepared by Oman Power and Water Procurement Company (OPWP) in 2011, waiting for approval from the Council of Ministers for installation of two projects of capacity around 200 MW at Manah and Adam in Oman. A study has been conducted for Direct Solar Radiation, Direct Normal Irradiance, Diffuse Horizontal Irradiance and Global Horizontal Irradiance, Temperature and Humidity in Sohar- Oman and compared with NASA SSE Model and Department of Meteorology-Oman. The solar radiation data has been measured houly in Renewable Energy Lab- Sohar University and get solar radiation more than 600 W/m^2 throughout the year (Hussein A Kazem, 2016). This specifies that in future Oman's energy necessities will be very high, which can be meet by installing more eco-friendly solar energy.

3.1 Climatic Data for Oman

Sultanate of Oman is situated on the south-eastern coast of the Arabian Peninsula. The weather of Oman is mostly arid but differs slightly from one area to other due to change in altitude. Within coastal region, the climate is hot and wet throughout the summer months, the maximum temperature in desert area recorded as 40^{0}C, whereas it's dry and inlands. In Oman there are solely two seasons, summer and winter. The duration of summer season will be from April to September, whereas the winter season lasts from November to March.

3.2 Oman's Insolation Data

The amount of solar energy focused on given area over a specified time, usually one day is called Insolation. Insolation is solar radiation incident at the surface of the earth, which is controlled by the sun's angle, altitude and state of the atmosphere. The monthly average global solar radiation on values horizontal surface per day has estimated for Oman. The estimation depends on the measurement of global solar radiation at ten major location in Oman. The board of Directorate General of Civil Aviation and Meteorology, Oman made solar radiation data to public for important information about the weather of Oman.

Table 1. Global solar radiation data for two cities in Sharqiyah Region in Oman (kWh/m^2/day)

Locations / Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Ibra	4.40	5.15	5.67	6.58	6.99	6.92	6.30	6.15	6.97	6.57	4.73	4.20	5.72
Sur	4.16	4.93	5.48	6.47	6.90	6.86	6.27	6.07	5.78	5.37	4.55	4.04	5.57

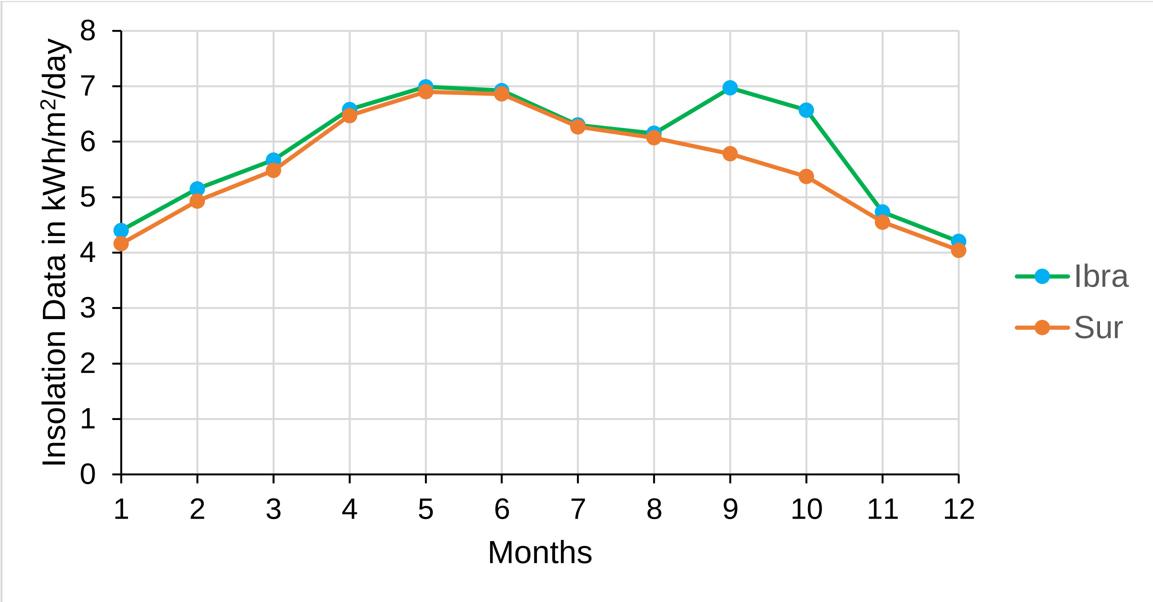

Fig. 5 Mean monthly insolation's data trends for Ibra and Sur from Table 1

The solar insolation value varies from yearly as well as place to place, in Al Sharqiyah region of Sultanate of Oman, paper has considered two cities at different locations. Al Sharqiyah region has two major cities Sur and Ibra, one in South Al Sharqiyah region and other in North Al Sharqiyah region respectively. This research compared global solar radiation data between two cities Sur and Ibra and represented in Table 1. Further, Table 2 shows the monthly temperature, relative humidity and air speed in Sur and Ibra, which further shown graphically in Figure 5 and Figure 6 independently for Ibra. The average global solar radiation over a horizontal surface area measured in kWh/m^2/day for two major cities in Sharqiyah region are as for Ibra 5.72 kWh/m^2 and for Sur 5.57 kWh/m^2 per day.

Table 2. Monthly temperature, air speed and relative humidity data for two cities in Sharqiyah Region

Months / Locations	Ibra				Sur			
	Temperature (^{0}C) Min	Temperature (^{0}C) Max	Air Speed on Earth (m/s)	Relative Humidity (%)	Temperature (^{0}C) Min	Temperature (^{0}C) Max	Air Speed on Earth (m/s)	Relative Humidity (%)
Jan	14.4	25.0	4.26	51.9	19.8	29.7	4.36	56.0
Feb	15.2	26.8	4.62	48.8	19.9	30.7	4.76	56.7
Mar	18.7	30.7	4.46	40.8	22.0	33.4	4.68	54.5
Apr	22.9	35.2	4.47	32.0	24.8	37.1	4.81	49.4
May	26.5	39.6	5.14	26.7	27.3	40.0	6.31	47.4
Jun	28.7	41.5	6.45	26.8	26.5	40.9	7.12	49.1
Jul	29.3	40.7	7.33	33.8	28.2	39.2	8.27	54.4
Aug	28.5	39.9	6.79	36.7	27.3	38.6	7.75	57.4
Sep	25.9	37.9	6.04	37.1	26.4	38.4	6.82	57.6
Oct	22.0	34.4	4.08	39.3	25.2	37.1	4.33	57.3
Nov	18.4	29.9	3.58	47.3	23.2	34.0	3.66	54.6
Dec	16.3	26.3	4.17	53.6	21.3	30.8	4.28	55.2
Average	22.3	34.0	5.11	39.5	24.3	35.8	5.59	54.1

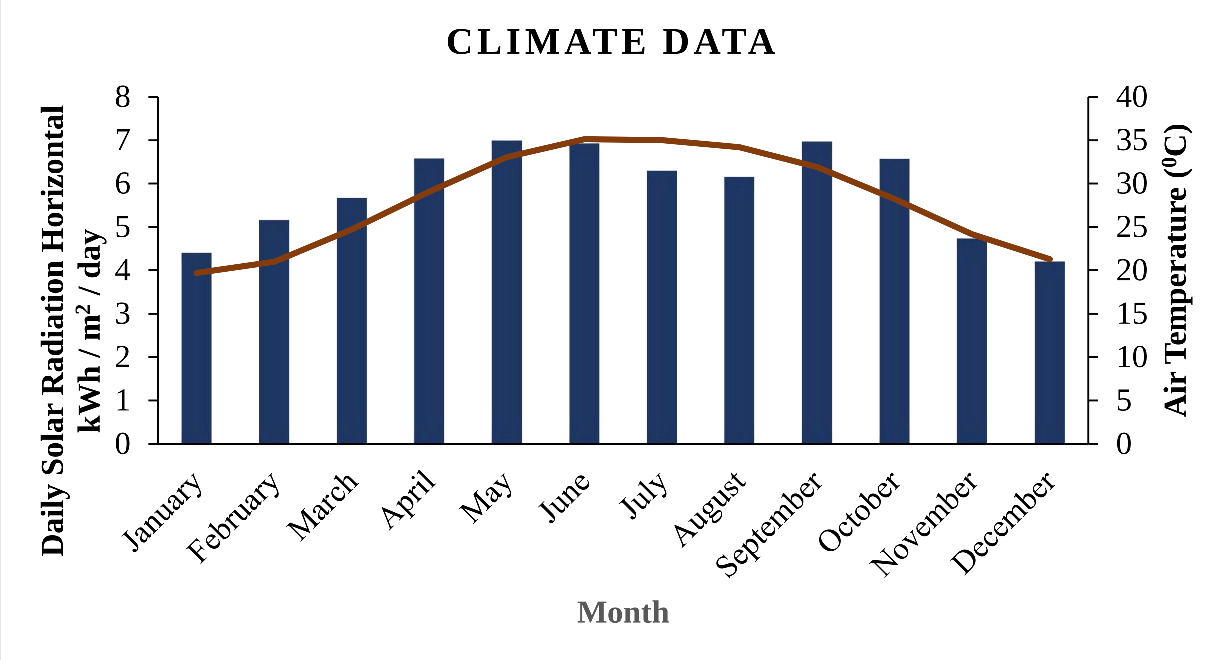

Fig. 6 Mean monthly insolation's data trends for Ibra from Table 1

3.3 Overall Evaluation of the Data

The average solar insolation information varies from 5.57 – 5.72 kWh/m^2/day, corresponding from 2033 – 2088 kWh per annum. Table 1 shows the maximum and minimum daily mean insolation for each month. Due to huge availability of solar resource in Oman theoretically, it has been observed that it can cover all energy demands of country as well as can export also. Due to extreme availability of solar energy in many parts of the country, it has been stated that Oman has highest global solar radiation data in the world. In desert area it has been found the highest solar irradiation whereas in coastal area it has been observed lowest solar radiation in Oman.

4. DESIGN AND OPTIMAL SYSTEM SIZING

4.1 Case Study for Power Requirement in a Laboratory

An electrical daily demand curve for a laboratory placed in colleges / Universities in Oman is important for optimal design of photovoltaic system to supply clean energy as renewable energy to reduce the initial setup cost and operating costs. In this research, during analysis it has been observed that the load curve will differ from 17800 W / h to 47250 W / h during one day in the month of summer showing diversified demand. Here, the maximum diversified demand can be computed as the total expected ratings of all connected electrical equipments during the interval of specified time. (Gelling, 1995) has defined the non-coincident demand as the distribution capacity required to meet the end-users maximum demands without keeping any restriction on the interval of specified time. Arvidson in 1940 developed a way to find distribution of loads in residential areas based on end users class load estimation from the distribution network by (Gonen, 2008). The cost of a solar PV system of suitable size for remotely placed village in India to supply satisfactory power backup used has been computed based on the analysis of power requirements (Sujit, 2016). Researchers have been found that performance of PV system improved after the cleaning the PV cells using sodium surfactant as well as alcohol. Even cleaning with distilled water reduced the performance of PV system by 14% after 6 weeks of exposure to atmosphere, due to the collected pollutants (Miqdam et al. 2015). The power requirement for Materials Laboratory at ICT, Ibra has been calculated as 47250 W-h/day, mentioned in Table 3.

Table 3. Appliances used in Materials Lab at ICT Ibra in Oman (summer)

Electric Appliances	Number of units	Power Rating (Watt)	Consumption of Power (Watt)	Used Hours / day	hrs×rating× no. used	Watts hour / day
AC	04	1500	6000	15	8×1500× 3	36000
Projector Computer System	01	250	250	4	4×250× 1	1000
Staff Computer System	01	250	250	7	7×250× 1	1750
Equipment connected to Computer System	01	250	250	4	2×250× 1	500
Lights	48	20	960	8	8×20× 40	6400

Projector	1	215	215	4	4×215× 1	860
Wireless access point	02	15	30	24	2×15× 24	720
Other resources like mobile charge, etc.	01	20	20	1	1×20× 1	20
Total			7975			47250

By anticipation of daily load for a particular device, it is easy to design a suitable photovoltaic system to provide electric supply to simple loads like a single water pump, electrical appliances or lights. On the other hand, for complex loads for a Laboratory major loads depend on the Lab classes timing, it is very complicate to forestall the uses of electrical appliances like daily used hours of A/C, Equipment's, Projector, lights, etc. For this reason, calculated watts hour should be multiplied by 1.2 as "fudge factor". Total power need for a lab has been computed as 47250 Wh / day = 47.250 kWh / day, which when multiply with 1.2 then power need is 56.7 kWh / day.

The quantity of solar radiation obtained at the solar panels over the fixed period of time during the poorest month of the year is called the "insolation value". Insolation value can be express in the kW-h/day. In Taxas, it has been observed the lowest insolation value available in the month of December, generally vary from 3.3 to 5.0 hours per day, which can be taken as reference to make a panel to work efficiently. The array size can be calculated by dividing the energy requirement daily by the fixed sun hour daily at this location. Then Inverter cost has been computed by considering the optimal size of a solar PV system, which is nearly around \$0.40 per watt.

Total Power requirement for a concerned Laboratory = 47.250 kWh/day

Total Power need to be considered = 47.250 × 1.2 = 56.7 kWh/day

Average Insolation data for a year = 5.72 kWh / m^2/ day

The capacity of a PV System Required

$$= \frac{56.7 \text{ kWh / day}}{5.72 \text{ kWh/ m}^2\text{/ day}}$$
$$= 9.913 \text{ kW}$$

The rating of a PV panel (considered) = 185 W

The average efficiency of panel has been considered in Oman context as 0.80

Number of panels required for same power

$$= \frac{9913}{185 \times 0.8} = 66.97 \approx 67$$

The cost of photovoltaic panel has been taken in this paper = \$5.50 per watt installed

Cost of 67 panel $= 185 \times 67 \times 5.50 = \$68172.50$

The panel dimension is around 1580 × 808 × 35 mm.

The inverter capacity = 10 KVA (minimum)

Inverter cost = 10000 × \$0.40 = \$4000

Hence total cost of a require solar PV system for a Laboratory is \$72,172.5

5. CONCLUSION

The main disadvantage of photovoltaic system is initial setup cost over the purchase cost of power from grid or diesel system, however, the more starting set-up cost of a photovoltaic system is acceptable due to high consistency and reliable within the complete life period of photovoltaic system, which further need very less maintenance as well as operation cost. Additionally, because the surroundings become one of the most concerns of the word nations. In terms of generation of power, photovoltaic system producing energy which has very less environmental impacts, any hazards and without noise. Generally, PV system producing very lower level of air pollutants that impacts the environment compare to more air pollutant by fossil energy. This paper focused the most important solar energy technologies and its demand by energy industry in Oman. The paper has studied the appropriateness of photovoltaic system for a Laboratory in Ibra College of Technology, Oman same can be applied to any University or separate Building.

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