Application of Solar Photovoltaic System in Oman – Overview of Technology, Opportunities and Challenges

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Received: 14.02.2013 Accepted: 04.04.2013

Abstract- Energy is considered as most important factor for the economic development of a country. Due to limited fossil resources and environmental problems associated with them, the need for other sustainable energy supply options that use renewable energies. Solar energy can play a vital role in providing most of the heating, cooling and electricity needs of the world, which is emerging as feasible option for electricity generation in future. This paper discusses the technology options, their current status and opportunities and challenges in developing solar photovoltaic (PV) system in the context of Oman. This paper also focused on the importance of global radiation data for the optimum design and working principles of PV system used for house appliances, water pumping, heating, etc. In this research, paper has considered two case studies for optimum selection of PV array to provide sufficient power back-up of a house remotely located and same for solar water pumping system to provide water to remotely located community. The paper presented the results of a research based on the survey of remotely located houses need electricity power during a day and to find a suitable PV model for a house based on solar radiation data available in Oman. The paper has also evaluated the economic feasibility of photovoltaic water pumping system in remote location in Oman.

Keywords- Solar Energy, Photovoltaic (PV), Solar Radiation, Solar Irradiance.

1. Introduction

The Sultanate of Oman lies between latitude 16^0 and 28^0 N and longitudes 52^0 and 60^0 E. Oman's 1700 km coastline extends from the straits of Hormuz in the north to the Arabian sea in the south. To the west lies the United Arab Emirates, the kingdom of Saudi Arabia and the Republic of Yemen. The Sultanate of Oman encompasses an area of 300,000 square kilometers. The country's climate is mostly arid, which varies slightly from one region to another. In the coastal areas, the weather is hot and humid during the summer months, while it is dry further inland. But at higher altitude locations the temperature will be generally high throughout the year. Winter temperature can be as low as 15^0C, while summer temperatures can be as high as 48^0C in the Muscat and 54^0C in the desert. Dhofar, located in the southern region of the country is having a regular monsoon between June and October, every year. The energy plays a vital role for the economic and social development of the nations. Due to easily availability of oil and natural gas in Oman as the cheap source of energy productions, but the future of oil as a form of energy is unsure, due to the limited supply of it and also due to its impact on environmental conditions due to emissions of CO_2, sulfur, etc. Now, time came to discuss on the availability of fossil energy resource, environmental impact of it versus various renewable resources and use of green power [1].

Due to fast growing of the global population and developing countries expand their economies so by 2050 the energy demand may be double or triple. The generation of electricity and its requirement has more impact on the economic development of any country. From 200 years major countries depends on fossil fuels for operating power plants, planes, trains, and automobiles, this leads to modifying the carbon cycle and additional greenhouse gas emissions. The result has been the debate on availability of fossil energy resources, peak oil era and timing for anticipated end of the fossil fuel era, environmental impact versus various renewable resources and use [1]. From last two decades, globally research and development has been carried out in the field of renewable energy resources due to its beneficial impacts on the environmental, economic, and political issues of the world [2]. Solar energy system is one of the fastest growing sources of renewable energy as an alternative source of energy having two technologies for the generation of power as solar photovoltaic and solar thermal [3]. An analysis has been done to find the carbon credits earned using standalone solar PV system which is encouraging the solar system by comparing the cost effective than conventional power generation [4]. The other viable option to control the carbon emission is substantial use of renewable energy along with the conventional resources. The Synergies of soft-computing techniques for improved solar cell models and control methods has been presented to increase the efficiencies of photovoltaic power plants connected to the electricity grid [5].

Photovoltaic (PV) is the technology to generate direct current (DC) measured in watts (W) or kilowatts (kW) from semiconductor materials when they are illuminated by photons. When the sunlight focus on the solar cell then it is possible to generate the electrical power but as sunlight stops, the electricity generation also stops. Solar cells are made of semiconductor materials, which weakly bonded electrons occupying a band of energy are called valence band. When energy applied to the valence electrons, the bonds are broken and electrons are free to move around the new energy band called the conduction band where it can conduct electricity through the material. Here, the energy needed to free the electron can be supplied by photons, which are particles of light. PV system can provide electricity to remote areas, which are away from the nearest electric grid connection, allowing the family members to have electric lights instead of diesel engines and can also run water pump to supply the water to remotely located community. PV system can also provide electricity to remotely placed transmitter stations. The energy generated by PV system is known as a secondary source of energy where as by fossil fuel (coal, petroleum and natural gas) combustion and nuclear fission are the primary source of energy to generate electricity. In PV system, certain numbers of solar cells are interconnected and encapsulated into units called PV modules, which produce DC current that can be transformed into AC current by using inverter. Till now in Oman, the application of solar energy is limited to very few applications like street lighting in cities, remotely located telecommunication station, etc [6]. The assessment and viability of electricity generation using photovoltaic cells has been analyzed by comparing with conventional gas turbine and concluded that PV stations are not economically feasible in Qatar. The application of renewable energy need high investment, but due to emerging of PV system of comparative lower cost can be implemented to remote areas [7].

The objective of this research is to identify the importance of the solar power technologies and its suitability in concerned of Oman. The research describes the trends in the development of solar energy technologies like PV system as the alternative energy resource for the economic and society development of the country. The PV technologies in this research has been examined for the energy generation and utilization of it as well as cost calculation of the panels used for water pumping system and for a typical house remotely located in Oman. In remote areas of Oman, underground water is considered the main life sustaining element. Presently, diesel engine is used for pumping water in remote areas which can be replaced by photovoltaic generators. The main problem take place due to diesel engine is difficulties of transporting the fuels, maintenance the equipment, which can be solved by green energy production by photovoltaic. Generally, solar photovoltaic pumping system composed of a photovoltaic solar array, a controller, a motor, a pump and a battery, etc. With development of a specific knowledge for the selection of energy converters to be installed, energy sources to be adopted in the use of renewable and non renewable energy and a reduction of CO_2 emissions due to the operation of buildings [8].

The main objective of this research is to estimate the size and cost of a proposed PV system for the application of a remotely located house and also for a solar water pumping system for a community in Oman. The rest of the paper is organized as follows: section 2 describes the Photovoltaic System Background to generate the power for water pumping system as well as for a typical remotely located. Then, paper focus on the Sultanate of Oman's Power Scenario in present and coming future described in section 3. After this, paper proposed and calculated the Solar System sizing and design based on the technologies presently available in the market in section 4 and finally, the paper discuss the results and presented conclusions in section 5.

2. Photovoltaic System Background

Solar energy or photovoltaic (PV) energy is the common form of renewal energy as a primary source with or without conventional power back-up. PV can be used from low power applications to high power applications like providing electricity in remote areas. Solar cells in PV made of semi conducting materials, which absorb sunlight and provide heat energy to freely move the electrons to produce electricity. Solar cells are usually combined into modules which further mounted in PV arrays of several meters in length. Flat-plate PV arrays can be mounted at a fixed angle facing the sun, or can be mounted on a tracking device that follows the sun to capture the most sunlight over the day. The number of PV arrays depends on the requirements of the electricity, as for example for house hold applications 10-20 PV arrays enough to provide power, while for large electricity demands, hundreds of arrays can be interconnected to form a single PV system. Figure 1 represents the PV array system.

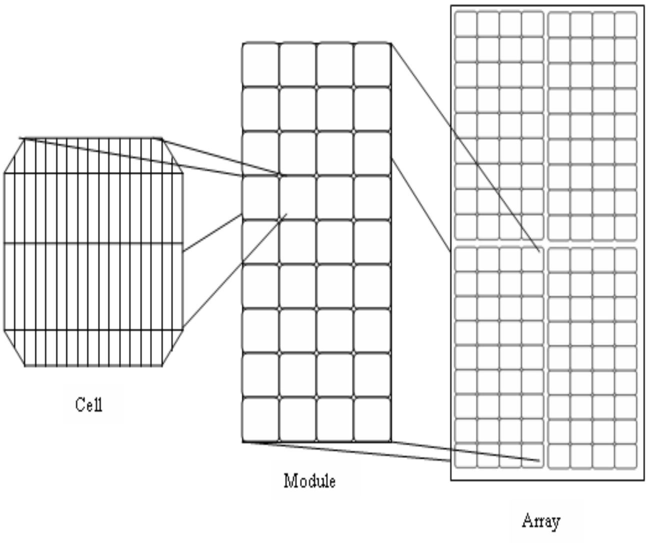

Fig. 1. Photovoltaic cells, modules and Arrays

Some solar cells has designed to build into concentrating collectors that used a lens to focus the sunlight onto the cells for increasing the performance, which is measured in terms of its efficiency at turning sunlight into electricity. When sunlight focus on cells some of this energy converted to electricity and other either reflected or absorbed by the materials of the cells. Normally it has been observed that a typical solar cell has an efficiency of 15%, to improve this efficiency it is required to put more number of arrays, which imparts cost of solar cell. Several researchers are working on to improve the performance and efficiency of solar cell while holding down the cost per cell. Recent advances in colloidal science are playing more important factors on the development of low-cost and/or high-efficiency solar cells [9]. Development of new materials with low cost causes the price of the technology in PV system coming down and increasing the demands of PV system globally with an annual rate of 35-40%, with PV technology of mono- and polycrystalline wafer Si solar cells [10]. The design of a novel building integrated photovoltaic/thermal (BIPVT) solar collector has been theoretical as well as experimentally analyzed and results showed that some design parameters like fin efficiency, thermal conductivity between PV cells, and lamination method have more impact on the efficiency of BIPVT [11]. With the assessment of renewable energy resources potential in Oman, it has been identified a barrier to their significant utilization. According to this research, solar and wind energy play an important role in the future energy in Oman if the higher authority will provide a clear policy for using renewable energy resources [6]. Due to unavailability of power lines in remote locations in developed nations like western US, Canada, Mexico and Australia solar photovoltaic water pumping (SPVWP) is a cost effective applications for remote water pumping. SPVWP has also significant advantages over diesel engine generator used for remotely placed locations for water pumping in terms of relative refueling and maintenance of generator [12]. Meah et al. [13] have presented the application of solar photovoltaic (SPV) based on its design, installation, site selection and performance monitoring of solar system for remotely placed water pumping system. They have also discussed the environmental and economic advantages of the SPV water pumping system compared to stand alone generator. A research has been conducted a techno-economic evaluation of off-grid hybrid photovoltaic-diesel-battery power systems for rural electrification in Saudi Arabia and found that the system has great opportunities in remote areas to meet the load requirements of a typical remote village-Rawdhat Bin Habbas with an annual electricity energy demand of 15943 MWh [14].

The cost of a PV system varies from countries to countries and also on the capacity of the array used in PV system. Generally, the cost varies from residential application (2 kW) of \$5.5/W to commercial application of capacity (700 kW) of \$5.6/W. The output of a PV module or system is a function of orientation, total irradiance, spectral irradiance, wind speed, air temperature, soiling and various system related losses. The PV array panels can be used as roof-mounting on tile or flat roofs, which is weathered proof and suitable for all climates. The efficiency of a PV system can be determined as:

$$\eta = \frac{P_{\max}}{E_{tot} \cdot A} \times 100$$

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

According to Antonio and Steven, [15] the performance of a PV system is based on the position of the sun by means of two angles that refer to the horizontal plane and to the vertical, respectively. One angle is the solar zenith angle θ_{ZS}, which is the angle between the vertical and the incident solar beam, i.e. is angle of incidence of beam radiation on a horizontal surface and the other angle is the solar azimuth ψ_s, which is between the meridians of the location and the sun i.e. the angular displacement from noon of the projection of beam radiation on the horizontal plane which can be given as:

$$\cos\theta_{ZS} = \sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega = \sin\gamma_S$$

$$\cos\psi_S = \frac{(\sin\gamma_S\sin\phi - \sin\delta)}{\cos\gamma_S\cos\phi}\left[\text{sign}(\phi)\right]$$

Where, δ is the solar declination angle, ϕ is the geographic latitude, ω is called the true solar time or solar hour is the difference between noon and the selected moment of the day in terms of a 360^0. $[sign(\phi)]$ means '1' for northern latitude and '-1' for southern latitudes and γ_s is the complementary angle of zenith angle, called solar altitude.

The angle of solar incidence between the sun's rays and the normal to the surface may be calculated from

$$\begin{aligned}\cos\theta_S &= \sin\delta\sin\phi\cos\beta - [sign(\phi)]\sin\delta\cos\phi\cos\alpha \\ &+ \cos\delta\cos\phi\cos\beta\cos\omega \\ &+ [sign(\phi)]\cos\delta\sin\phi\sin\beta\cos\alpha\cos\omega \\ &+ \cos\delta\sin\alpha\sin\omega\sin\beta\end{aligned}$$

The sun acts as a perfect emitter of radiation at a temperature close to 5800 K. The resulting power incident on a unit area perpendicular to the beam outside the earth's atmosphere, when it is 1 AU from the sun, is known as the solar constant B_0 = 1367 W/m^2. The radiation falling on a receiver situated beyond the earth's atmosphere, that is extraterrestrial radiation, consists almost exclusively of radiation traveling along a straight line from the sun [15]. Solar radiation is the fuel of solar energy systems so solar radiation data play vital role for designing and performance evaluation of solar energy system. Irradiance is the density of power falling on a surface is measured in W/m^2, where as irradiation is the density of the energy that falls on the surface over some period of time, for example, hourly irradiation or daily irradiation, and is measured in W h/m^2.

The amount of global radiation that reaches the receiver is extremely variable, which can be theoretically determined just by geometrical considerations [16]. For example, the extraterrestrial irradiance over a horizontal surface is given by $B_0(0) = B_0\varepsilon_0 \cos\theta_{ZS}$ which when integrated over the day give the average daily energy on a horizontal surface for that particular month given as:

$$B_{0d}(0) = \frac{T}{\pi} B_0\varepsilon_0 \left[-\frac{\pi}{180}\omega_S.\sin\delta.\sin\phi - \cos\delta\cos\phi\sin\omega_S \right]$$

where T is the day length that is 24 h.

The sunrise angle ω_S can be given as: $\omega_S = \cos^{-1}(-\tan\phi\tan\delta)$

2.1. Clearness Index

The relation between the solar radiation at the Earth's surface and the extraterrestrial radiation gives a measure of the atmosphere transparency. In this way, a clearness index K_{TM} is calculated for each month:

$$K_{TM} = \frac{G_{dm}(0)}{B_{0dm}(0)}$$

where, $G_{dm}(0)$ is the 12 monthly mean values of global horizontal daily irradiation. The clearness index is not only related to the radiation path through the atmosphere, but also with the composition and the cloud content of the atmosphere.

2.2. Peak Power Ratings

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

$$P = P_{\max}(E_{tot} \cdot T_a \cdot S)$$

Where, T_a is the air temperature, S is the wind speed and E_{tot} is the total plane-of-array irradiance measured with a pyrometer or radiometer [15].

2.3. Working principle of PV system

PV cells are made of at least two layers of semiconductor material, one layer as a positive charge and other as a negative charge. As sunlight focus on cell, some of the photons from light are absorbed by the semiconductor atoms, freeing electrons from the cell's negative layer to flow through an external circuit and back into the positive layer. This flow of electrons produces electric current. For improving the efficiency, dozens of individual PV cells are interconnected together in a sealed, weatherproof package called a module. Figure 2 represents the connection of two modules for getting desired output.

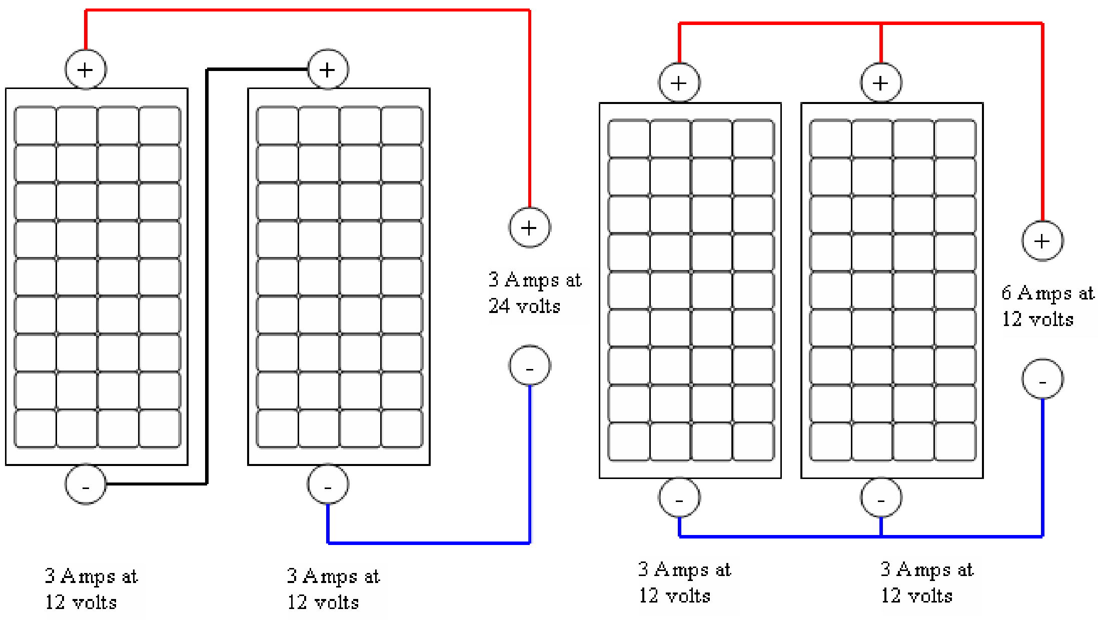

Fig. 2. PV System connected in series (left side) and parallel (right side)

When two modules are wired together in series, current remains constant where as voltage increased by two times. Similarly, when two modules are wired together in parallel, their current increased two times while voltage remains constant. To attain the desired voltage and current, modules are wired in series and parallel called PV array. Total power output from a PV panel array has been determined by multiplying the total output voltage by the total output current. In Oman there is huge quantity of solar energy available everyday, but not benefited widely due to the presence of primary fuel source in plenty amount as oil and natural gas for the generation of electricity. On the other hand, there are many remote areas using diesel for power generation and for water pumping system that can be replaced by using PV system, which has rarely impact on the environments.

3. Sultanate of Oman's Power Scenario

According to Power & Desalination Projects Market 2012, the total installed capacity and contracted generating electricity capacity of 4179 MW in Oman. Presently there is peak power shortage of about 10% and overall power shortage of 7.5%. The new power plant coming in Salalah, Sohar 2, Barka 3, and Sur is 3784 MW by 2014. There are 6 pilot projects on renewable energy of total generation capacity of 6.6 MW at an investment of 8.1 million RO has been used at different locations in the country. Further 6 power projects of capacity 11 GWh can be used to replace the power presently generated by diesel engine, if Rural Areas Electricity Company (RAEC) will allow for these projects, which can further save 3.1 million liters of diesel per year and avoid 8298 metric tons of CO2 per year [17]. According Annual Report of Oman Power and Water Procurement Company (OPWP) for 2011, OPWP is waiting a clear mandate from the Council of Ministers for the implementation of a commercial scale solar project of around 200 MW at Manah and Adam location in Sultanate of Oman. This indicates that Oman's future energy requirements are going to be very high and solar energy can be one of the efficient and eco-friendly ways to meet the requirement with eco-friendly.

3.1. Sultanate of Oman Climatic Data

Sultanate of Oman is a Middle Eastern country located on the south-eastern tip of the Arabian Peninsula. The country's climate is predominantly arid, however varies slightly from one region to another. In the costal areas, the weather is hot and humid during the summer months the maximum temperature can reach up to 40^0C in the deserts, while it is dry further inlands. In Oman there are only two seasons, summer and winter. The summer season starts in April and ends in September, the winter lasts form September to March.

3.2. Insolation Data in Sultanate of Oman

Insolation is the total amount of solar radiation that hits a particular location over a given period of time, typically a single day. Insolation data is always controlled by the sun's angle, state of the atmosphere, and altitude. The monthly average daily global solar radiation has been calculated using daily data of global solar radiation obtained by measurements at ten different locations in Oman. In this study, these data were taken from the monthly climate summary reports issued by the Directorate General of Civil Aviation and Meteorology, Oman, for each city. Global solar radiation varies from place to place, in Oman context paper has considered ten cities at different locations have been presented in the Table 1.

Table 1. Global Solar radiation data for different cities in Oman (kWh/m^2/day).

Months / Locations	As Sib	Suwaiq	Buraimi	Sur	Salalah	Ibri	Muscat	Fahud	Khasab	Sohar
Jan	4.08	4.13	4.02	3.64	5.14	4.03	4.08	4.61	5.36	3.84
Feb	5.09	5.08	4.56	3.83	5.71	4.99	5.09	4.91	5.97	4.76
Mar	5.54	5.51	5.28	4.44	6.32	5.41	5.54	5.64	6.58	5.23
Apr	6.40	6.31	6.06	5.36	6.87	6.29	6.40	6.39	6.92	6.15
May	7.03	7.02	6.75	5.75	7.26	7.05	7.03	6.89	6.89	6.91
Jun	6.91	6.90	6.39	5.44	6.70	7.08	6.91	6.78	6.11	6.92
Jul	6.27	6.23	6.03	5.03	6.20	6.44	6.27	6.25	5.92	6.23
Aug	6.11	6.06	6.06	4.89	6.06	6.20	6.11	6.25	6.17	6.09
Sep	5.89	5.87	5.94	4.64	6.35	5.97	5.89	6.11	6.5	5.81
Oct	5.48	5.47	5.36	4.42	6.02	5.37	5.48	5.61	6.28	5.29
Nov	4.50	4.49	4.33	3.69	5.27	4.56	4.44	4.64	5.44	4.23
Dec	3.90	3.97	3.72	3.17	4.79	3.88	3.90	4.17	4.92	3.65
Average	5.6	5.59	5.38	4.52	6.06	5.6	5.6	5.69	6.09	5.43

Average solar Insolation data measured in kWh/m^2/day onto a horizontal surface for different cities different values are: As Sib 5.6 kWh/m^2, Suwaiq 5.59 kWh/m^2, Buraimi 5.38 kWh/m^2, Sur 4.52 kWh/m^2, Salalah 6.06 kWh/m^2, Ibri 5.6 kWh/m^2, Muscat 5.6 kWh/m^2, Fahud 5.69 kWh/m^2, Khasab 6.09 kWh/m^2, Sohar 5.43 kWh/m^2 per day. Table 1 represented the insolation data for ten cities in Oman, which further represented in Figure 3 and Figure 4 separately for five-five cities so that it can be clearly shown the monthly average air-temperature.

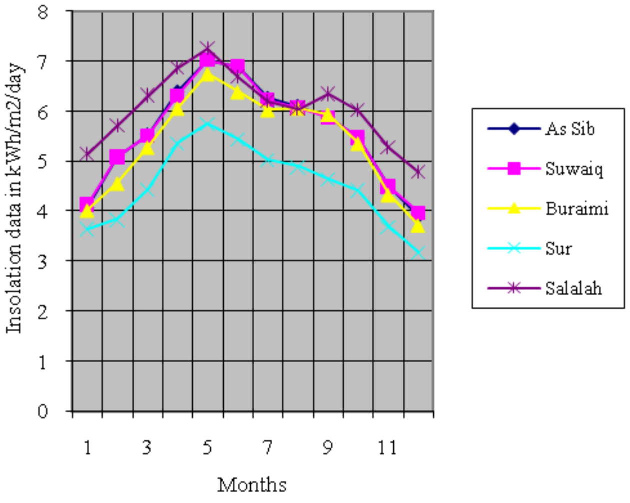

Fig. 3. Mean monthly insolations data trends for first five cities from Table 1.

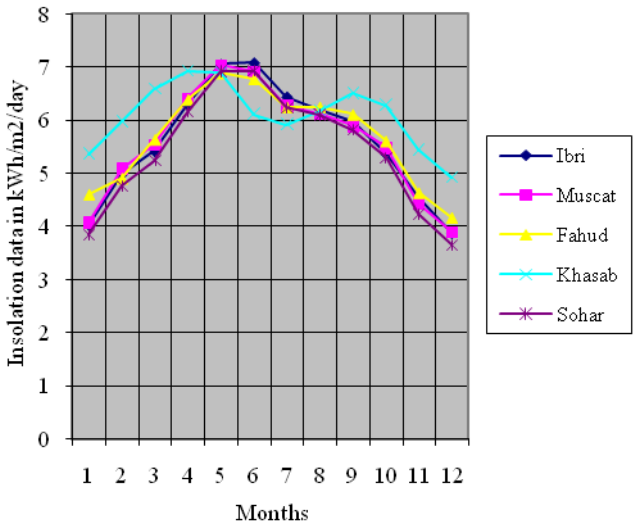

Fig. 4. Mean monthly insolations data trends for last five cities from Table 1.

3.3. General Evaluation of the Data

The average solar insolation data varies from 4.52 – 6.09 kWh/m^2/day, corresponding from 1650 – 2223 kWh per year. The difference between the highest and the lowest daily mean insolation within a month has been shown in the above Table 1. The difference is significant when the insolation is low. For a good location like Fahud the global insolation vary from 2.5 to 5 kWh per day in January, while the variation in July to September is only from 5 to 7 kWh per day. The yearly variation in average amounts to about 4.61 kWh/m^2 per day for January to about 6.89 kWh/m^2 per day for May in which the solar insolation is highest. From Table 1, it is clear that Salalah and Sur have a significantly lower insolation than other cities. In Salalah it is due to the summer rain period from July to September where as for Sur the reason is due to fog. The insulation in Seeb is high even though it is near the coast. The total solar energy resources in Oman are huge and can theoretically cover all energy demands and could provide for an export as well. High solar energy density is available in all regions of Oman. The solar resources in Oman are among the highest in the world. The highest solar irradiation has been found in the desert areas and the lowest solar irradiation has been in the coastal areas in the southern part of Oman. The level of the solar energy density in Oman is among the highest in the world.

4. Solar System Sizing Estimation

This paper has considered two case studies for generating solar energy for water pumping system as an alternative to the diesel powered pump and the solar energy generating for a typical house remotely located in Oman. The application of the PV pumping systems varies widely, depending on the requirements and the conditions under which water is pumped. The volume of water required also varies by season, time of day, and by the application that it's used for as well as the availability of the solar radiation. Basically, the solar pump is powered by solar energy, either directly by converting the solar resource into electricity or indirectly by using solar-thermal heat collectors. Though in this research, photovoltaic (PV) technology that is directly converts solar energy into electricity has been used and the PV array output depends on the intensity of the solar radiation striking the array. The amount of water delivered by the system depends mainly on the amount of solar radiation that is received by the system array.

Practically, brushless dc motors are the most attractive for smaller pumping applications and ac motors (integrated with inverters) are the most attractive for larger installations. Efficiencies of a motor-pump subsystem vary between 40 – 60 % depending on the motor, pump, and the power transmission. Normally, the optimum efficiency for motors is about 85%; for the pump about 70%; and for the suction and delivery pipe about 80%. Also the friction loss in pipes depends on the diameter and pressure in the pipe, as well as the amount and type of fittings used in the system. The capacity for a particular pumping application depends on the daily water requirement, pumping head and suction head. The most common type of pumps are submerged centrifugal motor pumps, submerged pumps with surface motors, reciprocating positive-displacement pumps, floating motor pumps and surface suction motor pumps. Normally, positive displacement pumps are best for low flows (less then 15 m3/day) and high pumping heads (30-150 meters). Submersible centrifugal pumps are best for high flow rates (25-100 m3/day) and medium heads (10-30 meters). Generally motors are grouped into two types as ac motors and dc motors. The simplest and cheapest type of ac motor is the squirrel-cage induction motor, which is having low cost and robust construction making it the suitable for PV applications. In contrast, ac motors are cheaper than dc motors and large ranges are available for different loads but it requires invertors for PV applications, which clearly add cost and increase breakdown risk. Electrical controllers and safety devices has been integrated into PV-water pumping system to control the electric power input to the pump. When more power produced, the controller automatically switched-off the pump, similarly, pump will switched-off if less power generated compare to specified minimum power rating of the pump.

4.1. 1st Case Study Photovoltaic Water Pumping System Sizing

This research has taken survey for Kabda village, which is located 24 km from Sur towards north in Oman. The houses in the village are dispersedly located not just adjacent to other house, so providing water to all houses needs more capacity of pump, which will increase the cost of the project. Here, the paper has considered the positive displacement pumps with ac motor of 1200 W. Basically, daily water demand and the total pumping head are the two main factors that identify what size of PV system can be implemented for the project. The average insolation data available in sur is 4.52 kWh/m^2/day, which is lowest value in all over ten cities. The daily water demand that is estimated on the basis of a water flow of 18 m^3 per day is sufficient to cover the requirements of a smaller rural community of around 100 people. The total pumping head is the total head that is required to pump water from the water source to the reservoir; that is the sum of the pumping head, the friction and the discharge head. The discharge head is the height from the surface of the ground to the reservoir pipe outlet. The average pumping head is estimated to be 35 meters. From the data given above, a PV water pumping system has been sized carefully and realistically. Ghonein presented the performance optimization of a PV powered water pumping system in Kuwait to fulfill the demands for 300 persons in remote area of the country based on the computer assisted simulation program. He also evaluated the feasibility of PV water pumping system in terms of cost compared to the conventional fuel system [18]. The research considered the economics of using photovoltaic technology for the remote areas in Upper Egypt and proved that PV-battery systems can be used efficiently for water pumping at East Owienat is less costly compared to diesel engine presented [19]. The cost-wise feasibility of the application of PV water pumping system compared to diesel engine in remote areas in Northern Badia of Jordan presented by considering many variables into account as the fuel prices, and the required investment [20]. PV/wind system has been proposed that would provide enough electricity for a settlement in rural areas [21]. Typically, commercial PV systems are installed at around $7-10 per watt. The force required to pump the water depends on the water volume required and the pumping head as well as the water density and gravity as follows:

$$F_H = d \cdot g \cdot \gamma \cdot A.H_{ef}$$

where, d is density of water, g is the acceleration of gravity, γ is the leakage coefficient (≈0.9), A is the cross-section area of the pump exit side and H_{ef} is the effective height.

To design a solar-powered water pump system, first it is necessary to determine the size of the system required, including the pump, PV panels, water tank size, etc. Following are the steps involved for proper estimating the capacity of the system required are as:

Step 1: Water Requirement

It is very important to determine the water demand per capita per day; normally it has been observed that a person can use 60 – 200 liters of water per day. In Oman, the average water demand per capita is around 150 liters. Water demand for a community can be determined by multiplying the water requirement per capita per day by number of people in the community. Here, it is 150 × 100 = 15,000 liters = 15 m^3, consider safety factor of 1.2, the total water demand = 18 m^3.

Step 2: Water Storage

A water storage tank is normally used to store enough water during peak energy production to meet water requirements in the event of cloudy weather or maintenance issues with power system. The paper has considered three days water storage capacity so total water requirement is 18 m^3/ day × 3 day = 54 m^3. To store this amount of water it is better to construct a water tank with cement and concrete mixture for long durability.

Step 3: Total Effective Head for the Pump

Total Effective Head (H_{ef}) = Vertical Lift + Pressure Head + Friction Head

Paper has estimated this effective head of 35 m.

Step 4: Pump Selection

The pump can be selected based on design flow rate and total effective head calculated value with the information available from the manufacturer’s pump curves.

$$\text{Hydraulic energy required, } E\,(\text{kWh / day}) = \\ Volume\ of\ water\ required\ (m^3 / day) \times \\ Head\ (m) \times water\ density \times gravity / (3.6 \times 10^6)$$

$$\text{where, gravity} = 9.81 \text{ and water density} = 1000 \text{kg / m3}$$

$$E = 18 \times 35 \times 0.002725 = 1.72 \text{ kWh}$$

Step 5: PV panel Selection

Now, the required load has been estimated to be around 1.34 kWh, the paper has considered that the pumping water system can be used for 6 working hours daily. The paper has considered the efficiency of the whole system, which consists of:

1. Pump: efficiency of 0.8

2. Motor: efficiency of 0.7,

3. Power electronics: efficiency of 0.9;

So, the entire system efficiency (η) = 0.9×0.8×0.7=0.5, then 1/0.5 = 2.

1.72 kWh × 2 = 3.44 kWh

Step 6: Cost of PV array (for DC supply)

The array size can be determined by dividing the energy needed by the number of available sun hours per day = 3.44/4.52 = 0.761 kW = 761 W

The cost of the PV array system required can be determined by multiply the size of the array by $10 per watt = 761 × $10 = $7610.

Step 7: Cost of PV array (for AC supply)

If an AC power supply to motor of pump, then system need an inverter and need more complex control system, which will add a cost of multiplying $1.2 by related watts: 761 × $1.2 = $913.2

Hence, Total estimated cost = $7610 + $913.2 = $8523.2

Step 8: Pump Selection and its cost

The important factors affecting the selection of a solar powered pump include:

1. Total Effective Head
2. The available electrical power and energy produced by the PV panel
3. The water requirement

A photovoltaic pumping system, pumping 18m3/day through 35 m head requires a solar array of approximately 761W. Such a pump would cost approximately $5500. This research has concluded that AC motors are more suitable, as AC motors are generally used for medium to high power demand applications and it is available in either single phase or three phases.

4.2. 2nd Case Study for Power Requirement in a House

PV system installed on the roof of the house can produce direct current power, just like the electricity produced by batteries. PV system composed of array, which has designed to generate specific amount of energy. In this study, paper estimated the number of panels needed to satisfy the requirements of power in that house. An electrical daily demand for a typical small house remotely located in Oman has been varied according to need, so it is very difficult to calculate the exact figure of load requirement at proper time. But this load requirement is essential for designing a power supply system based on solar radiation data available to reduce the capital and operational costs. On average, 6-9 people living in a house based on this information, in this research the load will vary from 1960 W/h to 10476 W/h during a day in summer has been evaluated based on the survey conducted of energy demand. Due to high initial investment costs, it is best for saving energy with appliances used in the household should be exploited as far as possible, rather than investing in a large system. Here, the maximum demand of power is the sum of the contribution of the electrical appliances used over a specified time interval. To determine the total load of appliances by multiplying the total number of hours used of an appliance by the ratings of the appliances and by number of appliances used at same time interval has been shown in Table 2. A research has defined the non-coincident demand as the demands of a group of loads with no restriction on the interval to which each demand is applicable presented in [22]. Arvidson in 1940 developed a method of estimating distribution loads in residential areas by the diversified demand methods presented in [23]. Table 2 present the requirements of power for appliances used in a typical house.

Table 2. Appliances used in a typical house in Oman (summer)

Electrical Appliances	Number of applications	Rated Power (Watt)	Total Power Consumption (Watt)	Hours Used/day	hrs×rating× no. used	Watts hour/day
AC	03	1500	4500	15	10×1500× 2	30000
Freezer	01	600	600	9	9×600× 1	5400
Fan	05	50	250	10	10×50× 3	1500
Refrigerator	01	460	460	10	10×460× 1	4600
TV	01	160	160	8	8×160× 1	1280
Coffee Pot	01	650	650	0.3	0.3×650× 1	195
Computer System	01	250	250	4	4×250× 1	1000
Vacuum Cleaner	01	900	900	0.2	0.2×900× 1	180
Washing Machine	01	1000	1000	0.5	0.5×1000× 1	500
Microwave oven	01	1300	1300	0.5	0.5×1300× 1	650
Mix-Grinder/Juicer	01	90	90	0.2	0.5×90× 1	45
Lights	10	20	200	8	4×20× 6	480
Vent. Fan	03	32	96	3	3×32× 2	192
Other resources like video/cassette recorder	01	20	20	1	1×20× 1	20
Total			10476			46042

For PV systems designed to power simple loads like a single water pump, electric light or other appliances, it is easy to determine the anticipated daily load. For complex loads like households, it is very complex to anticipate the electric load of appliances like daily used hours of TV, Coffee pot, fans, lights, etc. For this reason, calculated watts hour should be multiplied by 1.2 as “fudge factor”. Total power need for a house has been calculated is 46042 W-h/day = 46.042 kWh/day, which when multiply with 1.2 then power need is 55.25 kWh/day.

The amount of useful sunshine available for the panels on an average day during the worst month of the year is called the "insolation value". In Oman, the average solar insolation values range from 3.1 to 5.0 hours per day in December; this can be taken as reference to design PV panel so that it can work smoothly. The insolation value can be interpreted as the kW-h/day of sunlight energy fall on each square meter of solar panels at latitude tilt. The size of the array is determined by the daily energy requirement divided by the sun hours per day. 55.25 kWh/day is the power requirement and in Muscat minimum value of insolation data is 3.90 and its average value for a year is 5.6, hence 55.25/5.6 = 9.87.

Now, paper has considered PV panel rating of 185 W, which can be used for power production, then total no. of panels = 9870/185 = 54, hence, PV system will need 54 panels of rating 185 watt to produce the required power. The cost of PV panel has been considered as $5.50 per watt installed, so the total cost of 54 panels will be the cost of $ 54945.00 installed, where as the panel dimension is around 1580 × 808 × 35mm.

5. Conclusion

Typical solar radiation data is very important for designing and calculation of the size of the PV system. The initial cost of the PV system is the only disadvantage over the diesel engine, presently used as the alternative energy source in remotely location in Oman. However, particularly in remote areas the higher initial cost of the PV system can be justified by the savings in the lower operation and maintenance as well as the increased reliability throughout the useful longer life of the PV system, around 25 years. In addition, as the environment becomes one of the main considerations of the world nations, at the point of generation, photovoltaic energy generally produces no air pollution, hazardous wastes and no noise. In this paper, global solar radiation data for ten cities in Oman were presented in the Table 1. The paper has considered the suitability and feasibility of PV system for a house remotely located in Oman and replacement of existing diesel engine for water supply to remotely located community by PV water pumping system. This research has also computed the cost of PV array size need to satisfy the requirement for a remotely placed house as well as PV water pumping system.

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