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PHOTO-VOLTAIC SYSTEM

L. Pillay [1], Kh.S.Karimov [2]

1 - G.I.K. Institute of Engineering Sciences and Technology, Topi (District Swabi), 23460, NWFP, Pakistan.
2 -Physical Technical Institute of Academy of Sciences, Rudaki Ave, 33, Dushanbe, 734025, Tajikistan.

E-mail: zenvee_pillay@hotmail.com, khasan@giki.edu.pk

ABSTRACT

This paper describes a design of fixed photo-voltaic (PV) system that consists of four modules and two mirrors. In the system the modules and mirrors are installed at angled position of 90^o. Experimentally the voltage-current characteristics of the module in natural conditions and irradiance – time relationship for the modules installed in angled and line positions were investigated. Maximum power-time relationships were obtained showing that this system has higher output power as compared to PV system with line position of four modules. The PV system has a DC-DC (12 / 2 V) converter, DC-AC (12 / 220 V) inverter and a battery. The modules are able to provide an average power of ~ 100 W, which feeds the converter and the inverter. The total area of the four modules is 1.26 m^2. The inclination angle between the modules and the horizontal plane is adjustable ($34^o \pm 11^o$). The designed PV system produced the daily output energy equal to that of a tracking system with line position of the modules. The cost analysis data revealed that the proposed design is very economical and cost effective.

1. INTRODUCTION

Its undeniable fact that energy is an essential element for industrial and socio-economic development of a country. However, the linkage between energy and environmental pollution is one of the biggest challenges the world is facing today. In this context, the utilization of solar energy, which is environment-friendly, is important for sustainable development.

At present photovoltaic (PV) technology is used for conversion of solar energy into electrical energy in many countries around the world [1-7]. The solar electricity finds applications in a number of systems for instance: rural electrification; water pumping; satellite communications; grid-connected applications and corrosion protection such as cathodic protection for bridges, pipeline protection, well-head protection, lock gate protection and steel structure protection etc.

The efficiency of a PV system depends on several factors such as: a) natural climatic conditions of the place where the system is to be used; b) optimal matching of the system with the load; c) appropriate spatial placement of the modules, i.e., placing the modules at an optimal inclination angle to the horizontal plane and d) the availability of concentrators and / or solar tracking in the chosen system [8].

The majority of the PV systems used universally are the fixed solar modules however; the tracking systems are also used for low power applications [1, 2, and 4]. The tracking solar modules collect higher solar energy than that of the fixed solar modules [8]. At the same time the tracking systems are less reliable and more expensive because of the presence of electrical [9,10] or mechanical motors [4] and moving parts especially for utilization in remote areas where everyday maintenance is not present. On the other hand the tracking systems are more expensive due to additional sensing/driving solar modules [11-14]. In addition to that the sensing/driving solar modules, they are installed perpendicular to the basic modules, which increases the wind resistance of the system and thus makes it less reliable. In the majority of photovoltaic systems there is no mechanism to fix inclination angle of the modules in different seasons of a year. Photovoltaic systems with fixed in line position of modules are reliable but have lower efficiency with respect to the tracking systems. In this paper an economical solar photovoltaic system with fixed at angled position modules and mirrors has been designed with high efficiency and reliability.

2. EXPERIMENTAL, RESULTS AND DISCUSSION

The designed PV solar system has four modules of mono-crystalline silicon cells and two mirrors. The dimensions of each module and mirror are 115 cm x 27.5 cm, and the total area defined by the four modules is thus 1.26 m^2. Figure 1 shows the current-voltage characteristics of one of the modules at a solar irradiance, G = 800 W/m^2 (AM 1.5 spectral distribution) measured at the temperature of 25^{o}C at noon time (12 a.m.). From these characteristics, the open circuit voltage, V_{oc} = 17.4 V, short circuit current, I_{sc} = 2.1 A, maximum power, P_{max} = 27.4 W, fill factor, FF = 0.75 and efficiency, η = 11 % have been determined. Usually the daily output power of fixed photovoltaic system with line position of modules has maximum at noon time and is not uniform [4]. It would be possible to increase the output power of photovoltaic system in the morning and in the evening by installation of the modules in the angled position. As output power of the system depends on irradiance we investigated irradiance – time relationship for the angled (a) and line (b) positions of the receiver of solar radiation (Fig.2). The inclination angle (β) of the receiver in the direction from south to north was equal to the latitude of the GIK Institute (34^o). As a receiver the digital intensity meter was used. Fig.3 shows daily irradiance – time relationship for the angled (1 and 2) and line (3) positions of receiver schematically shown in Fig.2 . It is seen that angled positions (1) and (2) show higher irradiance in the morning and in the evening respectively with respect of line position (3). In the last case the irradiance is maximum at noon time. On the base of these experimental results we designed photovoltaic system with angled position of the modules. Taking into account that the plane mirrors are cheaper than modules and can increase the output power of the system it seemed reasonable to use them as simple and static concentrators.

Fig.4 shows schematic diagram of the photovoltaic systems with angled position of modules and mirrors combination (a) and with line position (b) of the modules. The four modules and two mirrors were divided into three pairs, mounted under angle α = 90^o. It is obvious that modules 1 and 2 as well as modules 3 and 4 would have more output power in the morning and in the evening time respectively and the modules 2 and 3 – at noon time when reflected irradiance from mirrors 1 and 2 are maximum.

The maximum output power (P_m) of the module may be calculated by the following expression [4]

$$P_m = J \times S \times \eta \qquad (1)$$

where J is irradiance, S is area of the module and η is efficiency of the module.

The maximum total output power (P_{tot1}) of the photovoltaic system with angled position of modules and mirrors may be obtained by the formula

$$P_{tot1} = S \times \eta\, [2\, J_1(t) + 2\, J_2(t) + \eta_{mr}\, J_2(t) + \eta_{mr}\, J_1(t)\,] \qquad (2)$$

where η_{mr} is mirrors' efficiency that is in this case time dependent and may be taken in the range of 70-90 % (in average it is equal to 80 %), $J_1(t)$ and $J_2(t)$ are irradiance of the modules # 1 and 2, and , 3 and 4 respectively (Fig.4-a).

For the line position of the four modules the maximum total output power (P_{tot2}) may be obtained by the following equation

$$P_{tot2} = 4\, J_3(t) \times S \times \eta \qquad (3)$$

Where $J_3(t)$ is irradiance of the line position of modules (Fig.4-b).

Fig.5 shows total maximum output powers (P_{tot1} and P_{tot2}) – time relationships for the angled and line positions of the photovoltaic systems. It is seen that during the day $P_{tot1} > P_{tot2}$, i.e. angled position modules has higher efficiency with respect to line position ones.

The maximum energy generated by photovoltaic system in the case of angled (W_{tot1}) and line (W_{tot2}) positions of modules may be determined by the following expressions

$$W_{tot1} = \int P_{tot1}\, dt \qquad (4)$$

and

$$W_{tot2} = \int P_{tot2}\, dt \qquad (5)$$

from the curves of Fig.5 (from t=9-00 to t=16-30); W_{tot1}= 950 (W hr) and W_{tot2}=835 (W hr).

The relative efficiency (E_{ff}) of the angled position of modules with respect of line position of ones may be determined by

$$E_{ff} = (W_{tot1} - W_{tot2})\, 100\ \% /\ W_{tot2} \qquad (6)$$

and it is equal to 14 %. It means that designed PV system with angled position of modules shows better performance than that with line position of modules and actually its output power is close to that of PV tracking systems [4].

Fig.6 shows electric circuit of photovoltaic system in the case of one output (a) and two output (b) connections. For the angled position of modules circuit of Fig.6-b is preferable because modules M1 and M2, as well modules M3 and M4 are in the similar positions respectively (Fig.4) and illuminated under the same irradiance.

3. CONSTRUCTION AND BASIC ELEMENTS OF PV SYSTEM

The construction of PV system (Fig. 7) consists of a pyramidal stand whose two upper edges are made with fixed length and lower edge have movable and immovable parts to make them variable in length in order to fix the inclination angle (β) of modules at 23^o, 34^o (latitude of the G.I.K. Institute) and 45^o. On the upper edges of the pyramidal stand four modules and two mirrors in angled position are installed.

Fig. 8 shows the block diagram of the PV solar system. Charge regulator, DC-DC (12 / 2 V) converter and DC-AC (12 / 220 V, 50 Hz) converter circuits are conventional ones that are used widely in practice [15, 16]. Estimated average output power of the system is 100 W. DC output may be used for corrosion protection in industry and the AC output for domestic applications in remote areas.

4. COST AND BENEFIT ANALYSIS OF THE DESIGNED PV SYSTEM

As far as the economics of PV systems is concerned there are some special considerations [4, 5] such as; the initial expenditure on the equipment which is usually high but there is no fuel cost involved, maintenance cost is low, reliability of the systems is high therefore the replacement cost is also low, and the output of the system depends upon the location of installation. Accumulated data show that at present a PV system is competitive where small amounts of energy are required at a place that is far away from an electric grid or any other source of energy. For the economic evaluation of a system, the parameters that are usually considered are [4] life-cycle cost (LCC), payback period (PP) and rate of return (RR). LCC is the sum of all the costs of a system over its lifetime, expressed in today's money. In case of the analysis of a PV system, the lifetime of the modules is usually taken as 20 years. For a detailed analysis it is important to use the following parameters; present worth (PW) which is the equivalent value in today's economy of the future costs (future cost should be multiplied to discount factor calculated from discount rate), period of analysis (the lifetime of the longest-lived system under comparison), excess inflation (the rate of price' increase of a component above general inflation), discount rate (the rate at which money would increase in value if invested), capital cost (the total initial cost of buying and installing the system), operation and maintenance (the amount spent each year in keeping the system operational) and replacement cost (the cost of replacing each component at the end of its lifetime). The calculations were made on the basis of the approach described in reference [4].

For the comparison of a PV and TEG systems it would be reasonable to take into account the time that is needed before the energy is generated and is available for utilization from these systems. For a PV system that time is around 6 hours and 24 hours for the TEG system: however, a PV system in fact can supply power 24 hour a day due to the flexibility of storing energy in a battery. Considering this the total life-cycle costs of the two systems may be considered as ~ \$1592 and ~ \$2817 respectively.

The cost of a 'unit' of the generated electricity is one of the valuable figures for electricity-generating systems. This can be determined by the relationship given in reference [4].

Our results of estimated electricity cost matched with those reported in reference [4] for the PV, diesel generator and grid-extension systems. Our analysis shows that the cost of electricity from a PV system is approximately equal to that from a diesel generator and cheaper than a grid extension. The analysis also shows that the PV system is cheaper than the thermal electric generator as well, which is used for corrosion protection. This PV system may be used for domestic applications especially in remote areas.

Keeping in view the environmental impact and economical assessments of the designed PV system, it is evident from the listed data that that the PV system even at present is a competitive choice for small power requirements. As predicted in [4] the expected reduction in the cost of solar modules to \$3/W_p in future, a PV system may also become economically more attractive option for the higher loads as well.

5. CONCLUSION

A fixed photo-voltaic (PV) system was designed which consisted of four modules and two mirrors. In the system the modules and mirrors are installed at angled position of 90^o. The angled modules/mirrors combination was mounted on pyramidal stand. Experimentally the voltage-current characteristics of the module in natural conditions and irradiance – time relationship for the receivers of solar radiation installed in angled and line positions were investigated. Maximum output power-time relationships was calculated for the PV system with angled position of modules and mirrors, it also showed that this system has higher output power as compared to PV system with line position of four modules. The PV system has a DC-DC (12/2 V) converter, DC-AC (12/220 V) inverter and a battery. The modules are able to provide an average power of ~ 100 W, which feeds the converter and the inverter. The total area of the four modules is 1.26 m^2. The inclination angle between the modules and the horizontal plane is adjustable ($34^o \pm 11^o$). The designed PV system produced the daily output energy which is actually close to that of a tracking system with line position of the modules.

The PV system may be used in rural and remote areas as a power supply for low power applications such as cathodic protection system and domestic power requirements. Cost analysis of the proposed photovoltaic solar tracking system showed that it is cheaper or comparable than any other power generation system for low power applications.

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REFERENCES

[1] J. W. Twidell and A. D. Weir, Renewable Energy Resources (E & F.N. Spon, London, 1986).

[2] Renewable Energy: Power for Sustainable Future, edited by G. Boyle (Oxford University Press in association with the Open University, New York, UK, 1996).

[3] China: New & Renewable Energy (A white book by China Planning Press, 1999).

[4] Solar Electricity, Edited by T. Markvart (John Wiley & Sons, New York, 2000).

[5] G. T. Wrixon, A.-M. E. Rooney, and W. Palz, Renewable Energy–2000 (Springer-Verlag, Berlin Heidelberg, 1993).

[6] Z. I. Zaidi, I. Ahmed and P. Akhter, in:Proc. Workshop on Renewable Energy Technologies: Dissemination and Market Development, 3-6 April 2000, (Islamabad, Pakistan, 2000) 156-173.

[7] P. Akhter,in : Proc. Workshop on Renewable Energy Technologies for Clean Environment and Sustainable Development, 26-29 March 2002 (Amman, Jordan, 2002)15-25.

[8] Kh.S. Karimov, J. A. Chattha, M. M. Ahmed et al., Journal of Academy of Sciences of Tajikistan, Vol.XLV, No.9 (2002) 75-83.

[9] S. Dadamukhamedov, R. A. Muminov, M. N. Tursunov and M. Khamrit, Solar Engineering, No.5 (1998) 86-88.

[10] V. Poulek and M. Libra, Solar Energy Materials and Solar Cells, 51 (1998) 113-120.

[11] F. G. Kelly et al., Spacecraft Altitude Detector Utilizing Solar Sensors and Summation of Predermined Signals Derived Therefro, US Patent 3.493.765.

[12] G. A. Zerlaut et al., Solar Tracking Devic, US Patent 4.031.384.

[13] G. L. Haywood et al., Solar Collectors and Drive Circuitry Control Mean, US Patent 4.082.947.

[14] J. M. Gordon and H. J. Wenger, Solar Energy, 46 (1991), pp. 211-217.

[15] N. Mohan, T. M. Undeland and W. P. Robbins, “Power Electronics”, John Wiley & Sons, New York, 1995.

[16] R. S. Ramshaw, “Power Electronics Semiconductor Switches”, Second Edition, Chapman & Hall, New York, 1994.

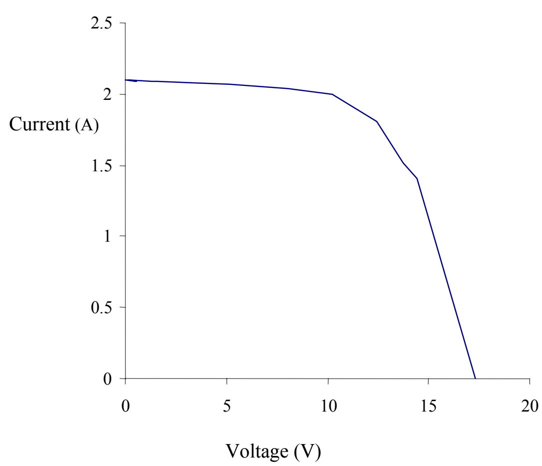

Fig. 1 Current-Voltage characteristics of a solar module.

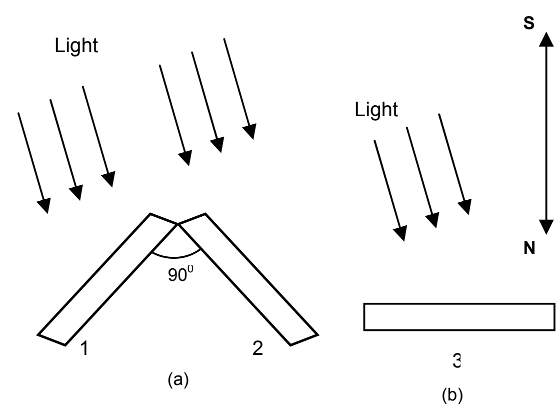

Fig. 2 Angled (a) and line (b) positions of the receiver of solar radiation.

Time	Position 1	Position 2	Position 3
9	900	210	600
10	960	395	800
11	810	600	900
12	678	740	905
12.5	640	790	917
14.5	295	990	875
15.5	195	900	700
16.5	167	810	360

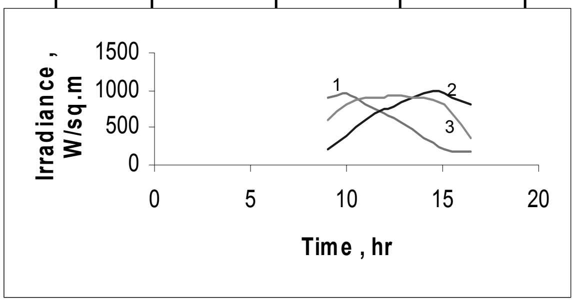

Fig. 3 Irradiance – time relationship for the receivers shown in Fig.2

Time	Ptot1	Ptot2
9	112	84
10	133	111
11	137	125
12	138	126
12.5	139	127
14.5	126	122
15.5	110	95
16.5	95	50

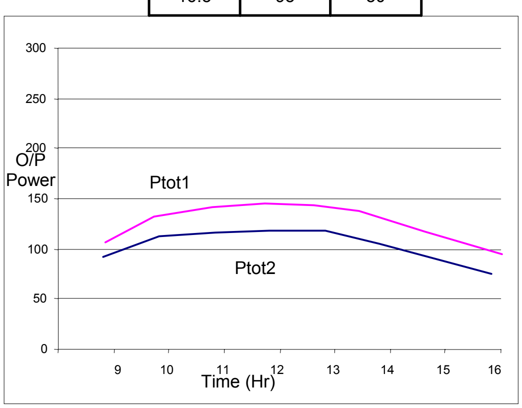

Fig. 5 Maximum output power – time relationship for the PV system in the case of angled (1) and line (2) position of modules .

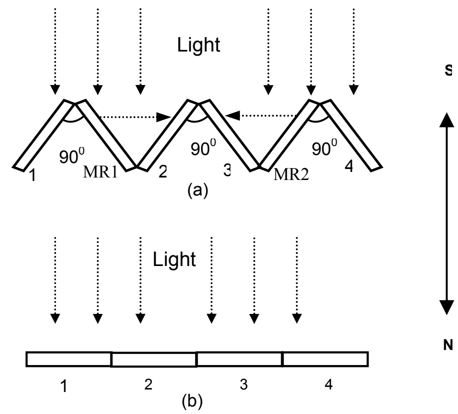

Fig. 4 Angled position (a) of four modules and two mirrors and line position (b) of four modules in PV system: 1-4 are modules, MR1 and MR2 are mirrors.

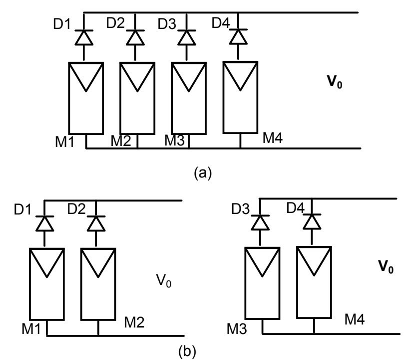

Fig. 6 Electric circuit of PV solar system in the case one output (a) and two outputs (b) : M1-M4 – modules, D1 - D2 – blocking diodes.

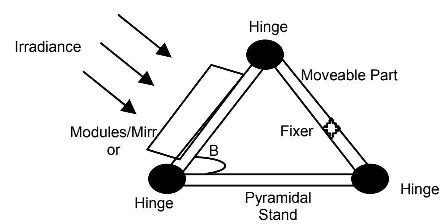

Fig. 7 Construction of PV solar system.

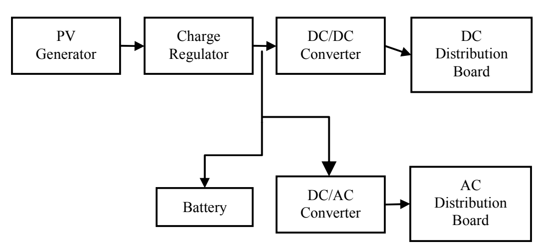

Fig. 8 Block-diagram representing PV solar system.