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PHOTOVOLTAIC PERFORMANCE UNDER REAL DESERT CONDITIONS NEAR CAIRO

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Abstract—A photovoltaic panel of polycrystalline silicon solar cells from Solarex was installed with a tilt angle of 30°. The temperatures of the centre and side of the panel were measured by two thermocouples, in addition to the global radiation and ambient temperature measurements. The measurements were analyzed to determine empirical models for the temperature effect and the resultant power. It was found that there is a drop in the voltage and power of the photovoltaic panel at noon during the spring and summer seasons.

INTRODUCTION

A great deal of work is being carried out on solar cells with the aim of obtaining the highest possible power under the influence of the exterior conditions such as solar radiation and temperature, in measuring the two main parameters I and V (short-circuit current and open-circuit voltage) of solar cell systems [1, 2].

In the case of silicon cells in the photovoltaic conversion of solar energy, there is a rapid drop in the efficiency of the semiconductor solar cell with temperature rise and at 160–180°C the silicon cells have zero efficiency. Thus, when photovoltaic assemblies are coupled to solar radiation concentrators, some form of cooling is necessary [3, 4].

The relation between light intensity and short-circuit current I is linear: I increases with increasing light intensity due to the increase in the number of photons generating the photo current in addition to the perceptible improvement in I with increase in temperature, which is the consequence of the improvement in the diffusion lengths and due to the shift of the absorption edge to lower energies [5, 6].

From the following equation:

$$V_{oc} = \frac{AkT}{q}\ln\left[\left(\frac{I_{sc}}{I_o}\right)+1\right]$$

which shows the logarithmic relation between V and light intensity and also shows that V is a function of the light intensity, dark current (I) and the junction perfection factor (A), one can conclude that the dark current (I) decreases and V consequently increases with increasing band gap or decreasing temperature.

Egypt is characterized by a hot desert climate in the summer, where the maximum temperature of the ambient air ranges between 35°C in the North (Cairo) and 42°C in the South (Aswan) on average. This hot climate decreases the output voltage and conversion efficiency of the silicon solar cells, during the optimum time of solar energy utilization [7, 8].

In the present work, the system is employed using normal panels without special attachments for cooling and light concentrating.

MEASUREMENTS

The short-circuit current of solar cells is not strongly temperature dependent. It tends to increase slightly with increasing temperature. This can be attributed to increased light absorption, since semiconductor band gaps generally decrease with temperature. The other cell parameters, the open-circuit voltage and the fill factor, both decrease [9]. For this reason, in the present work, a photovoltaic panel containing 40 polycrystalline solar cells from Solarex of type Sx–110 was installed facing South with tilt angle of 30° (the latitude of Cairo) on the roof top of the building of the National Research Institute of Astronomy and Geophysics (NRIAG) near Helwan at Cairo in the arid desert land area.

The system shown in Fig. 1 was constructed to measure the temperature of the solar cells at the centre

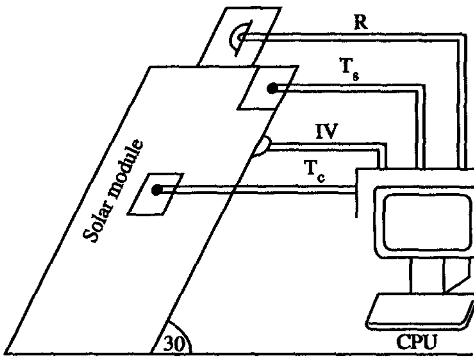

Fig. 1. Experimental setup.

of the panel and near its edges by using two thermocouple sensors. The temperature of the ambient air was measured simultaneously to that of the solar cells for comparison. The normal incident beam, global, and diffuse solar radiation were recorded by instruments of the Eppley type. Also, a doom sensor for measuring the global radiation on the surface of the PV panel was installed in a parallel position. The measurements were carried out from morning to sunset to provide variance in the solar radiation. Also, measurements for the environment's meteorological conditions were performed every hour.

EMPIRICAL MODEL

The average module temperature is given as follows:

$$T_{av} = (T_c + T_s)/2 \quad (1)$$

where T_c is the temperature of the cell in the centre of the panel and T_s is the temperature of the cell in the side of the panel. From our analysis the relation between the average polycrystalline silicon module temperature and the ambient air temperature is given by the empirical equation:

$$T_{av} = -27 + 2.49T_a - 0.0166T_a^2 \quad (2)$$

where T_a is the ambient temperature. Also, the relationships between the ambient temperature and T_c and T_s are given by:

$$T_s = -33.081 + 2.793T_a - 0.02072T_a^2 \quad (3)$$

$$T_c = -28.626 + 2.642T_a - 0.01669T_a^2. \quad (4)$$

The following empirical equation gives the relationship between T_c and T_s as follows:

$$T_c = 1.146T_s - 2.29. \quad (5)$$

The instantaneous array output power P_{out} over the day at a given time t (local civil time) is given as:

$$P_{out} = a - bt + c\cos(td + e) \quad (6)$$

where a is the mean daily output power from the panel (W); b is the degradation of the electrical energy from the panel (J); c is the amplitude of the daily values (W); d is local civil time constant $(1/t)$; e is the phase constant corresponding to the true noon; and t is zonal time in hours. The values of the above constants is given as follows: $a = 28.303$ W; $b = 0.248$ J; $c = 27.724$ W; $d = 0.423\ \mathrm{h}^{-1}$; $e = 1.249$.

Using the empirical eq. (6), there is a good correlation between the equation and the measured data as shown in Fig. 5.

The average daily electrical energy produced by the panel can be found by integrating the instantaneous array output (eq. 5) over the day from sunrise t_1 to sunset t_2:

$$E = \int_{t_1}^{t_2} P_{out}(t)\,dt \quad (7)$$

where E is the average daily electrical energy; $E_{out}(t)$ is the output power of the panel as a function of time; and t is the time period in hours.

Equation (6) can be expressed in terms of the panel efficiency as follows:

$$E = A \times \tau \times H_{tilt} \times \eta$$

where A is the cell area; τ is the transmissivity of the array cover; h_{tilt} is the average daily irradiation per unit area on the tilted array surface; and v is the average array efficiency.

RESULTS AND DISCUSSION

The three different components of the solar radiation (horizontal global, tilted global and direct) are shown in Fig. 2. The figure shows that the maximum

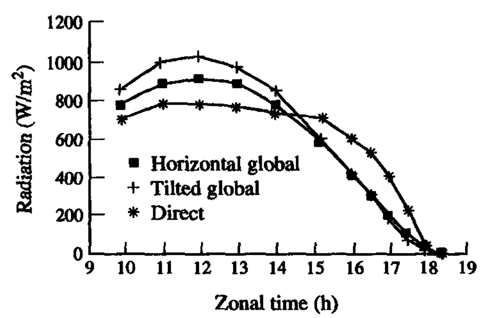

Fig. 2. The variation of different components of solar radiation with time.

energy power is received around noon for the global tilted panel compared with the direct and horizontal components; for this reason the panel is installed in a tilted position for conversion efficiency optimization.

Figure 3 shows the variation of the central temperature (T_c), side temperature (T_s) and ambient temperature (T_a) with zonal time t. The temperature of the central solar cell is always greater than the temperature of the side solar cell by about five degrees on average through the day, and reaches its maximum value at true noon. The degradation of the ambient temperature is small as compared with both the side and central cells except at true noon.

The variation of the output voltage and current of the panel through the day is shown in Fig. 4. The curve shows a small drop in the output voltage at noon due to the temperature effect which is responsible for decreasing the band gap energy of the cell.

The theoretical output power due to empirical eq. (6) and experimental power (measured data) are plotted in Fig. 5. The curve shows a good coincidence between the theoretical and experimental electrical powers.

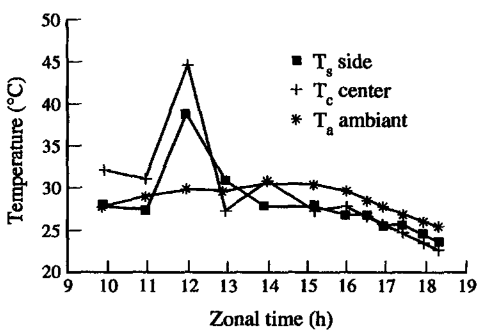

Fig. 3. The variation of T_s, T_c and T_a with time.

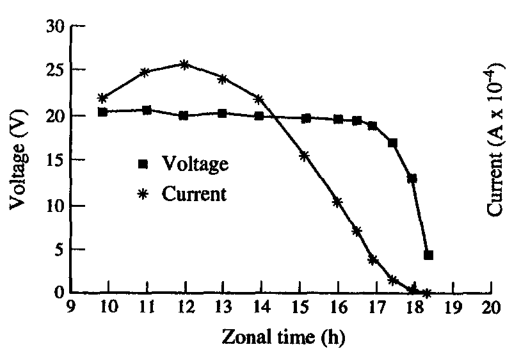

Fig. 4. The variation of output voltage and current of the panel through the day.

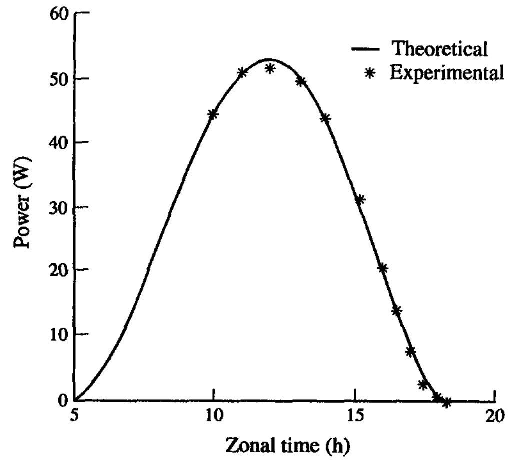

Fig. 5. The variation of output power with time.

The variation of the panel efficiency with zonal time is shown in Fig. 6. The figure shows a drop in the conversion efficiency at true noon and the curve gradually decreases until sunset.

The relation between the temperature of the central and side solar cells is linear as shown in Fig. 7 and is given by the empirical eq. (6) as expressed previously.

CONCLUSIONS

From all the previous measurements and discussions, we obtain the following conclusions.

(1) The central temperature of the polycrystalline module reaches 48°C at noon and is greater than the ambient temperature by about 18°C (at insolations of 1000 W/m^2 on tilted panels). This causes a drop in the efficiency of about 0.5% which is not sufficient to use a cooling system.

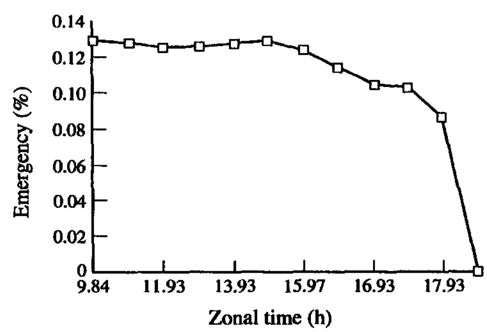

Fig. 6. The variation of efficiency with time.

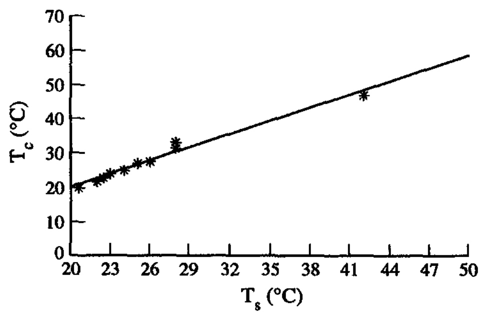

Fig. 7. The relationship between the temperature of the central and side solar cells.

(2) The relation between the central temperature and side temperature of a model shows a good linear correlation and a degradation factor of five degrees.
(3) The effect of the average temperature of the silicon polycrystalline module in eq. (2) causes a drop in the output voltage parameter at noon, thus the resultant conversion efficiency decreases at noon in the hot desert.
(4) There is a good coincidence between the output resultant power of the empirical eq. (5) and the experimental data.

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