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The Effect of Temperature on Photovoltaic Cell Efficiency

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ABSTRACT

As a great potential renewable energy source, solar energy is becoming one of the most important energies in the future. Recently, there has been an enormous increase in the understanding of the operational principle of photovoltaic devices, which led to a rapid increase in the power conversion efficiencies of such devices. Solar cells vary under temperature changes; the change in temperature will affect the power, output from the cells. In this paper a relation between efficiency, sun radiation and temperature is proposed and under cloudy climate is simulated and temperature ambient PV module for a desired efficiency can be obtained.

KEYWORDS: Photovoltaic Cell; PV Efficiency; Temperature; Cloudy Climate

1 INTRODUCTION

Recently, the massive consumption and exhaustion of fossil fuel resulted in enormous interest to utilize renewable sources of energy such as solar energy. Photovoltaic power is an established technology and has recently experienced rapid growth over the last ten years (Xiao et al., 2008).

A solar cell basically is a p-n semiconductor junction. When exposed to light, a dc current is generated. PVs offer several advantages such as: high reliability, low maintenance cost, no environmental pollution, and absence of noise (Patel et al., 2008).

The equivalent circuit of the PV cell is shown in Fig 1.

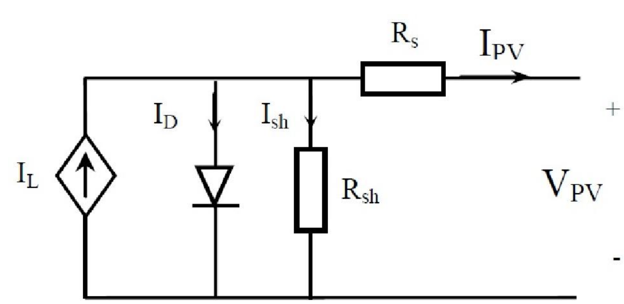

Figure 1: Equivalent circuit of the PV cell

The PV curves vary with solar insolation and module temperature. Equation (1) and (2) are used to describe the characteristics of PV array.

$$I_{pv} = I_l - I_o(e^{q(V_{pv}+I_{pv}R_s)/AKT} - 1) - \frac{V_{pv} + I_{pv}R_s}{R_{sh}} \tag{1}$$

$$P_{pv} = V_{pv} \times I_{pv} \tag{2}$$

Where: I_{PV} is the PV module current (A), I_L is the light generated current (A), I_o is the diode saturation current, q is the charge of electron (coulomb), K is the Boltzmann's constant (j/K), A is the diode factor, T is the module temperature (K), R_S is module series resistance (ohm), R_{sh} is module parallel resistance (ohm), V_{PV} is the module output voltage (V), and P_{PV} is the extracted PV power (W). (Azab., 2010).

2 EFFECT OF TEMPERATURE ON PV PERFORMANCE

Solar cells vary under temperature changes. The change in temperature will affect the power output from the cells. The voltage is highly dependent on the temperature and an increase in temperature will decrease the voltage.

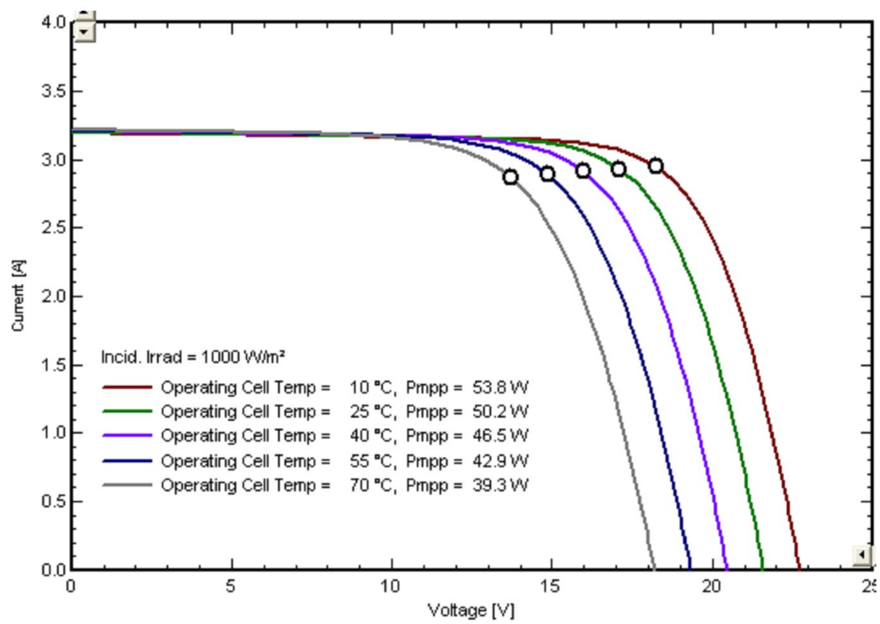

Figure 2: Output I-V characteristics of the PV module with different temperatures

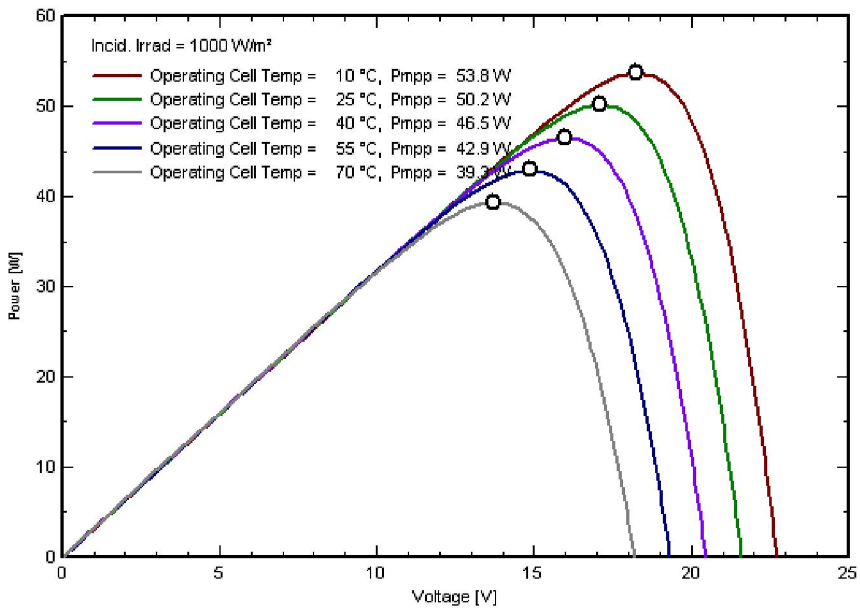

Figure 3: output P-V characteristics of the PV module with different temperatures

Figure 2 shows the effect of temperature on I-V characteristic of PV module at constant radiation (Qiang and Nan., 2010). With decreasing temperature, PV current decrease slightly but PV voltage increase clearly. As figure 3 indicates, output power of photovoltaic module increases with decreasing temperature.

2.1 PV Module Efficiency as a Function of Operating Temperature

The solar cell power conversion efficiency can be given as:

$$\eta_c = \frac{P_{max}}{P_{in}} = \frac{I_{max} \times V_{max}}{I(t) \times A_c} \tag{3}$$

Where I_{max} and V_{max} are the current and voltage for maximum power, corresponding to solar intensity (I(t)) and A_C is Area of solar cell (Tiwari and Dubey., 2010).

The correlations expressing the PV cell temperature (T_c) as a function of weather variables such as the ambient temperature (T_a), solar radiation (I(t)), etc. will be discussed in this section. The effect of temperature on the electrical efficiency of a PV cell/module can be obtained by using the fundamental equations.

The basically effect leads to a relation in the form:

$$\eta_c = \eta_{Tref}[1 - \beta_{ref}(T_c - T_{ref}) + \gamma \log_{10} I(t)] \tag{4}$$

In which η_{Tref} is the module's electrical efficiency at the reference temperature, T_{ref}, and at solar radiation of $1000 W/m^2$. The temperature coefficient, β_{ref}, and the solar radiation coefficient, γ, are mainly material properties, having values of about 0.0045K and 0.12, respectively, for crystalline silicon modules (Notton et al., 2005).

The quantities η_{Tref} and β_{ref} are normally given by the PV manufacturer. However, they can be obtained from flash tests in which the module's electrical output is measured at two different temperatures for a given solar radiation flux (Hart and Raghuraman., 1982). The actual value of the temperature coefficient, in particular, depends not only on the PV material but on T_{ref} as well. It is given by the ratio:

$$\beta_{ref} = \frac{1}{T_o - T_{ref}} \quad (5)$$

In which T_0 is the (high) temperature at which the PV module's electrical efficiency drops to zero (Garg and Agarwal., 1995). For crystalline silicon solar cells this temperature is 270 °C (Evans and Florschuetz., 1978).

The steady-state power balance determines cell temperature: the input is the absorbed luminous power, which is partially converted into useful electrical output and the rest is dissipated into the surroundings. Convection is the main mechanism for heat dissipation in terrestrial, flat plate applications, and radiation is the second nonnegligible mechanism of heat dissipation. A common simplifying assumption is made that the cell-ambient temperature drop increases linearly with irradiance. The coefficient depends on module installation, wind speed, ambient humidity and so on, though a single value is used to characterize a module type. This information is contained in the Nominal Operating Cell Temperature (NOCT), which is defined as the cell temperature is measured under open-circuit when the ambient temperature is 20◦C, irradiance is 0.8 kW/m^2 and wind speed is 1 m/s. T_{NOCT} usually values around 45 °C.

For variations in ambient temperature and irradiance the cell temperature (in ^{o}C) can be estimated quite accurately with the linear approximation (Luque and Hegedus., 2003) :

$$T_c = T_a + \frac{T_{NOCT} - 20}{0.8\,\mathrm{kw/m}^2} \times I(t) \quad (6)$$

If substitute equation (6) in equation (4) we will obtain important equation (7):

$$\eta_c = \eta_{ref}[1 - \beta_{ref} \times [T_a - T_{ref} + (T_{NOCT} - 20) \times \frac{I(t)}{I(t)_{NOCT}}] + \gamma \log_{10} I(t)] \times 100 \quad (7)$$

Authors usually consider T_{ref} =25°C, average η_{ref}= 12% and average β_{ref} = 0.0045K.

2.2 Simulation

Consider a day sometimes is sunny and sometimes is cloudy and solar intensity varies with time frequently. Assume I(t) = 1000+500sin(t/5), as we can see in figure 4, efficiency decrease with temperature increase and by increasing time, efficiency varies because of frequent variation of sun radiation, so efficiency varies with temperature and sun radiation.

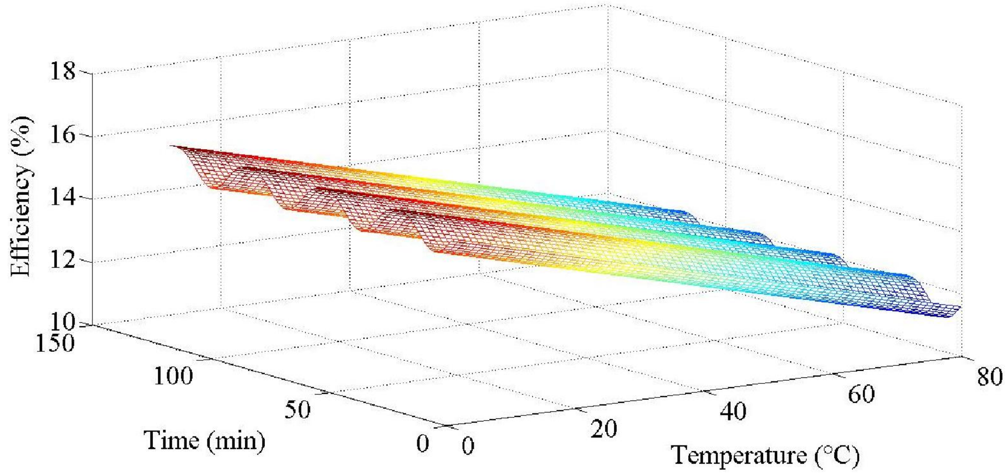

Figure 4: Variation of efficiency with different temperatures and I(t)=1000+500sin(t/5)

Figure 5 shows variation of efficiency with temperature at solar radiation of 1000W/m^2. There is a linear relation between ambition temperature and module efficiency. Decreasing temperature results more efficiency. So for a desired efficiency of a photovoltaic module we can determine what temperature ambient of module is needed, so by changing temperature around PV module we can operate efficiency.

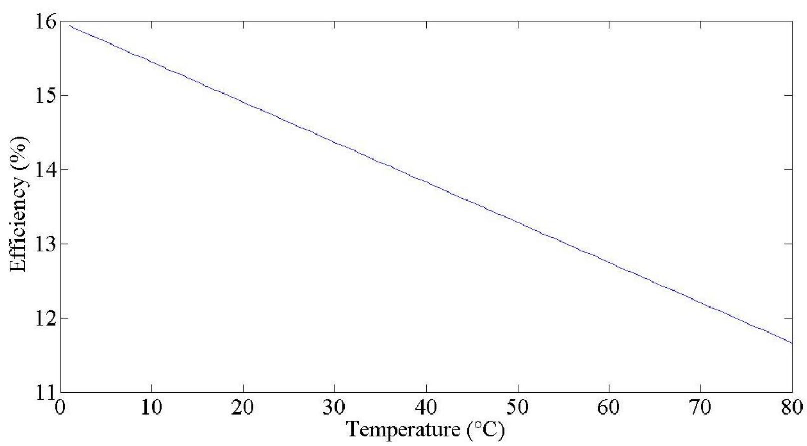

Figure 5: Photovoltaic cell efficiency versus temperature

Photovoltaic cells are limited in efficiency by many losses, some of these are avoidable but others are intrinsic to the system, so decreasing temperature very much, surely doesn't result efficiency increase.

3 CONCLUSION

In this paper the effects of temperature on photovoltaic modules investigated and by using basic equation a relation between efficiency, sun radiation and temperature is proposed. The effect of temperature on efficiency of photovoltaic module in cloudy climate indicated. The present work clearly indicates a decrease in the efficiency of the PV module with increase in temperature. For a particular PV module we can find out for a desired efficiency what temperature ambient PV module is needed.

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