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A Review in Context to Wind Effect on NOCT Model for Photovoltaic Panel

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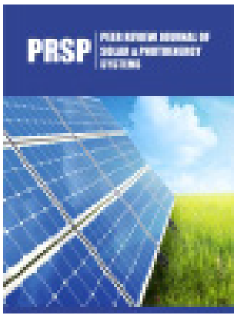

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Abstract

This study aims to consider the Nominal Operating Cell Temperature (NOCT) model for the photovoltaic (PV) module by adding the wind effect via experiment equation. The resulting model presents a linear wind convection heat transfer equation; the PV module temperate indirectly changes with wind speed. On the other hand, the efficiency of the PV module is directly correlated to the wind speed, as is expected and reported in the literature. This study suggests an approach how can insert the wind heat transfer equation into the NOCT model.

Keywords: PV module, Solar, Wind, Heat transfer, Efficiency, Numerical

Introduction

The heat energy generated in the PV panel and converted to electricity is a function of many factors related to module properties and the environment. A large portion of the solar flux wasted in the panel appears as heat transfer. This amount of heat is generated by the release of photons in semiconductor materials in internal processes. Therefore, standard heat transfer such as convection and radiation must be applied to the energy balance of the solar panels.

In a particular case of installing photovoltaic panels, the heat transfer mechanism loses to the environment and thus increases the photovoltaic module's efficiency. Due to the structure of the photovoltaic panel in a steady-state condition, radiation and convection are the only methods of heat transfer from the surface to the environment [1,2].

In steady-state energy equilibrium, predicting the surface temperature of a photovoltaic module requires the following data:

a. Physical and thermal properties of photovoltaic cells

b. Solar radiation and meteorological information

c. Heat transfer coefficients of convection and radiation

Regarding the heat transfer coefficients, several experimental relationships are recommended for heat transfer through wind, which provides an acceptable result under certain conditions [3]. T_C is the temperature used to predict the electrical performance of the module; however, this temperature may be higher than the surface temperature behind the module, which is called Tb. The difference temperature between the front and backside of the module depends on the material of the modulus and the intensity of the solar flux, and the following equation defines the relationship between these two temperatures [1]:

$$T_c = T_b + \frac{G_T}{G_{ref}} \Delta T_{G_{ref}} \quad (1)$$

Where G_{ref} is the reference of the solar flux with amount 1000W/m^2, G_T is simultaneous solar flux in W/m^2, T_b is a temperature of the backside of the module in °C, TC is the PV surface temperature in °C, and ΔTG_{ref} is difference temperature on front and backside of the module in reference condition in °C [1,2].

In this study, the method of obtaining T_C is through energy balance in the cell or module requires the use of the Nominal Operating Cell Temperature (NOCT). The set temperature of the device in the nominal conditions of the earth environment, solar radiation is 1000W/m^2; ambient temperature is 20 °C, average wind speed 1m/s, open circuit, and the module is perpendicular to the solar noon [1,4,5].

$$NOCT = (T_c - T_a) + 20\ ^{\circ}C \quad (2)$$

In the NOCT method, it is assumed that the ambient temperature is the same on both sides of the module. T_C- T_a's temperature difference is specifically dependent on T_a and is linearly related to solar radiation flux [1,5]. Overall, the total heat loss coefficient U_L is approximately constant and is obtained by testing the NOCT [1]. This approximation does not consider the effects of wind speed, humidity, and temperature on U_L. However, these factors can significantly affect U_L [6]. The relationship of energy balance in stable conditions is described as follows [2]:

Electric power generated by photovoltaic panel = Lost power - Absorbed solar power, which in arithmetic presentation is:

$$\eta_C G_T = (\tau\alpha)G_T - U_L(T_c - T_a) \quad (3)$$

Where η_C is the module's efficiency in converting the solar radiation into electrical energy, τα is the transmittance-absorption multiplier which gives the absorbed energy multiplied by the solar radiation. The efficiency varies from zero to the maximum efficiency of the module, depending on how close the module is to the optimum operating point. The loss coefficient U_L includes losses by convection and radiation from above and below surfaces and through the conduction [7]. All losses occur at ambient temperature T_a. Applying the NOCT condition for the PV cell will have η_C = 0. The installation method has a significant effect on the NOCT, so if the cells are not installed in the same way as they were installed in the defined conditions, care must be taken in using the NOCT. With arithmetic simplification and substituting equation (3) in equation (1) [1,2],

$$T_c = T_a + \left(\frac{G_T}{G_{NOCT}}\right)\left(\frac{U_{L,NOCT}}{U_L}\right)(T_{NOCT} - T_{a.NOCT})\left[1 - \frac{\eta_c}{(\tau\alpha)}\right] \quad (4)$$

Equation (4) does not consider the PV cell temperature variation with wind speed unless the ratio of the two lost coefficients is known [6]. This work aims to employ the available convection heat transfer for the wind to rewrite the NOCT equation with wind speed effects.

Theory

It skillfully addresses the PV module temperature in steady-state condition could be defined with the simple equation as follow:

$$T_c = T_a + KG_T \quad (5)$$

In this linear equation, which is considered without load and no wind effect, K is introduced as the Ross coefficient. This equation clearly determines the ambient temperature is increasing with higher solar flux as follows [8]:

$$K = \frac{\Delta(T_c - T_a)}{\Delta G_T} \quad (6)$$

When the panel is exposed to wind, the reported value for K is in the range of 0.02 to 0.04 °C m^2/W [1,9,10]. The implicit equation for PV module temperature could be defined as following [1,5]:

$$Tc = Ta + \left(\frac{T_{NOCT} - T_{a.NOCT}}{G_{NOCT}}\right)G_T \quad (7)$$

Equation (7), in comparison to equation (4), has a similar pattern. As long as (η_C /τα) is negligible compared to a unit, equation (7) is applicable [9]. This equation shows the linear correlation between T_C and G_T. This assumption causes an approximately 2 to 3 °C error in calculating the photovoltaic panel temperature. In the solar flux 600W/m^2 and τα = 0.9, the η_C is assumed without load then η_C = 0 [1,3].

U_L is involved in convection heat transfer, so it is possible to replace ($U_{L',NOCT}/U_L$) in equation (4) with a proportion of wind-heat transfer convection ($h_{w,NOCT}/h_w$) in significant windy conditions. A convective heat transfer via wind is defined as follows [1]:

$$h_w = 8.91 + 2V_f \quad (9)$$

At NOCT condition: wind speed is 1m/s and then $h_{w.NOCT}$ = 10.91W/m^{2}K, G_{NOCT} = 800W/m^2 , $T_{a,\ NOCT}$ = 20 °C. For siliocon PV modules $T_{C,NOCT}$ = 47 ± 2 °C. Applying this properties inequation (9) with respect to equation (4), gives this analytical-experimantal equation:

$$T_c = T_a + \left(\frac{0.32}{8.91 + 2V_f}\right)G_T \quad , \quad V_f > 0 \quad (10)$$

Substituting equation (10) is the linear efficiency experimental equation presents the efficiency as follow:

$$\eta_c = \eta_{ref}\left[1 - \beta_{ref}\left(T_a + \left(\frac{0.32}{8.91 + 2V_f}\right)G_T - T_{ref}\right)\right] \quad (11)$$

Where T_{ref} is standard measurement condition, η_{ref} is PV module efficiency at T_{ref}, β_{ref} is PV cell temperature parameter. At T_{ref} = 25 °C efficiency for Silicon PV module is η_{ref} = 12% [1,10].

Result and Discussion

This study is considered NOCT methods for PV module temperature, which does not sens the wind effect on the PV module temperature. In a numerical approach, the wind effect is substituted in the NOCT equation and describe these statements:

a. The significant wind speed generates forced convective heat transfer and inversely affects the PV module temperature.

b. The wind affects the PV module efficiency directly

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