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TWO METHODS FOR MODELLING OF PHOTOELECTRIC CONVERSION IN ENERGY ANALYSIS OF BUILDINGS

DWIE METODY MODELOWANIA KONWERSJI FOTOELEKTRYCZNEJ W ANALIZIE ENERGETYCZNEJ BUDYNKÓW

Abstract

Nowadays, there is a growing interest in using of renewable energy sources, especially solar energy which can be converted into electricity by photovoltaic panels. In addition to traditional stand-alone photovoltaic systems, more and more new or modernized buildings are equipped with integrated photovoltaic systems (BIPV). The main aim of this paper is to compare two models used to calculate amount of electric power generated by photovoltaic panel. Analysed models were implemented into well-known simulation programs, ESP-r and TRNSYS.

Keywords: photoelectric conversion, mathematical models, simulation

Streszczenie

W dzisiejszych czasach można zaobserwować rosnące zainteresowanie wykorzystaniem źródeł energii odnawialnej, zwłaszcza energii promieniowania słonecznego, która m.in. za pomocą systemu fotowoltaicznego może być przekształcona na energię elektryczną. Poza tradycyjnymi wolnostojącymi panelami fotowoltaicznymi w nowych i modernizowanych budynkach, coraz częściej stosowane są systemy PV zintegrowane z budynkiem. Głównym celem tego artykułu jest porównanie dwóch modeli stosowanych do obliczania ilości energii elektrycznej wytworzonej przez fotowoltaiczny panel. Analizowane modele zostały wdrożone do znanych programów symulacyjnych, ESP-r i TRNSYS.

Sowa kluczowe: konwersja fotoelektryczna, modele matematyczne, symulacja

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Nomenclature

λ – ideality factor parameter which define losses caused by imperfections in PV material

a – ratio of solar radiation absorbed in PV material at test conditions

a_T – modified ideality factor

e – charge on an electron, $e = 1.6 \times 10^{-19}$ [C]

q_{sw} – solar radiation absorbed in solar cell [W]

I – current flowing from solar cell [A]

I_D – diode current [A]

I_g – current which flows in solar cell when no light is present [A]

I_L – light current [A]

I_o – diode reverse saturation current [A]

I_{sh} – current through shunt resistance [A]

I_{sc} – short circuit current [A]

k – Boltzmann constant k = 1.38×10^{-23}

P – predicted power [W]

P_{max} – maximum power point [W]

R_s – series resistance

R_{sh} – shunt resistance

T – absolute temperature of solar cell [K]

V – voltage of solar cell [V]

V_{oc} – open circuit voltage [V]

1. Introduction

1.1. Modelling the BIPV

Appropriate modelling of a BIPV system in energy simulation software is very complex and difficult. Photovoltaic systems are susceptible to the influence of many environmental factors, such as solar radiation, temperature, angle of incidence and spectral distribution. Moreover, some hard to predict factors also affect the efficiency of the PV cells: ageing, mismatch, soil, dirt, snow and shading [1].

Furthermore, manufacturers provide only basic parameters of their products, for instance the open circuit voltage, the short circuit current and nominal efficiency. All these data are available at standard test conditions, where the irradiance is 1000 W/m², the cell temperature is 25°C and spectral distribution equivalent to air mass is 1.5. In reality, PV systems often work under higher temperatures or a lower value of solar radiation. Therefore, efficiency of photovoltaic panels is lower than given by the manufacturer.

On the other hand, photovoltaic modules are characterized by their current versus voltage curve (*I–V* curve) (Fig. 1). The shape of the *I–V* curve is largely dependent on irradiance and temperature [2]. Besides, technology of the solar cell (mono-crystalline, poly-crystalline, thin film or triple junction amorphous) also has influence on electrical characteristics.
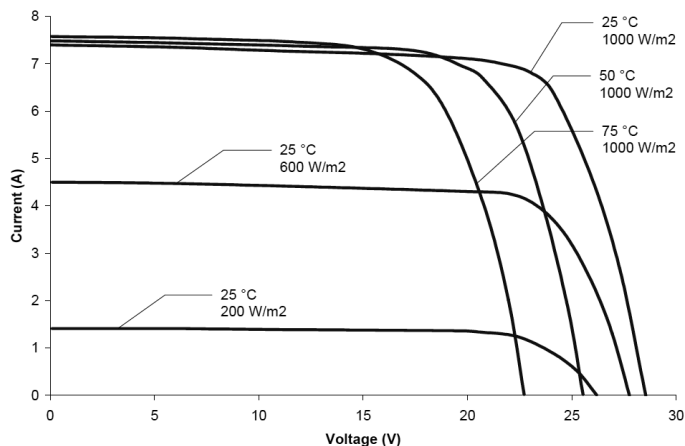
Fig. 1. *I–V* curve characteristic for PV model [1]

1.2. Computational methods

Many different computer programs were developed in order to estimate renewable energy produced from photovoltaic. Methods used to determine photovoltaic conversion can be more or less complex, according to the purpose of its use. Some simple methods take into account constant efficiency of energy conversion to estimate electrical power produced by photovoltaic cells. Others are characterized by very complex approach considering the dependence of conversion efficiency from temperature and intensity of solar radiation. These sophisticated methods include many factors such as cell temperature, radiation, shading as well as the heat exchange with adjacent surfaces and surrounding.

2. The ESP-r PV model

Building integrated photovoltaic components was implemented into ESP-r as a multi-layered construction model. A photovoltaic panel integrated into building facade consists of four layers of material: outer glazing, PV material, resin binder and inner glazing. PV material is formed as a middle layer consisted of a number of solar cells and determine in form of a 'special material'. Moreover, the PV material is a hybrid thermal/electrical component, because solar radiation absorbed by the photovoltaic material is converted simultaneously into heat and electrical energy [3].

A layer of PV material is represented by three thermal control volumes: two outer, mixed-property control volumes and one central, homogenous control volume. The thermophysical properties of each control volume are defined in individual nodes. Central thermal control volume is augmented with electrical control volume due to an additional calculation of the power produced by the PV material. Electrical characteristics of each solar cell, assigned as the electrical control volume, are determined by an equivalent circuit model. The electrical properties for each solar cell are defined as individual node *i* [3].

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Into ESP-r are implemented three models of photovoltaic systems. Two of them were developed by Kelly (1998): a simple efficiency-based model and a one-diode equivalent model (Fig. 2). The second one is a basic ESP-r model. The calculation of power output are made using short circuit current and open circuit voltage without consideration of the temperature-dependence of these two variables. Hereafter, the basic equations characteristic to one-diode equivalent model describing the amount of power generated by the solar cell are presented.
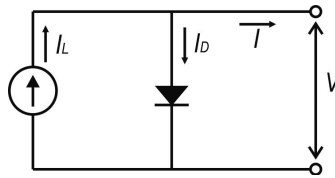

Fig. 2. Simple equivalent one-
-diode circuit [1]

The current balance equation for a solar cell is calculated from Kirchhoff's current law [3]:

$$I = I_L - I_D \tag{1}$$

$$I = \frac{q_{sw}}{a} - I_g \left(\exp\left[\frac{eV}{\lambda kT} \right] - 1 \right) \tag{2}$$

The power output from the individual solar cell can be defined by equation (3), [3]:

$$P = VI = \frac{Vq_{sw}}{a} - VI_g \left(\exp\left[\frac{eV}{\lambda kT} \right] - 1 \right) \tag{3}$$

Third model, applied in 2005 is developed on the more complete equivalent circuit model which contains representation of the series resistance (Fig. 3) [4]. Moreover, it is based on the WATSUN-PV model and considers the dependence of the short circuit current, open circuit voltage and the maximum power point on the temperature [5].

Simulation results for both ESP-r's models were compared with monitored data [4]. It was found that both of them correctly predict the shape of the power versus time curve. However, they over-predict the amount of direct current (DC) power generated at mid-day.

3. The TRNSYS PV model

Power generated by photovoltaic array in TRNSYS can be calculated using 4-parameter or 5-parameter PV model. The 4-parameter model was mostly developed by Townsend

in 1989 and implemented by Eckstein (1990) [6]. The name of the method indicates four independent parameters used in equation of the equivalent circuit: light current (I_L), diode reverse saturation current (I_o), series resistance (R_s) and ideality factor (a_T). The required parameters are generally available from the PV modules producers. Afterwards, the model was improved and developed into a 5-parameter model. Main properties of this model were presented by de Soto (2005) [7, 8]. The power provided by a PV panel is calculated based on a more complex equivalent one-diode circuit model containing shunt resistance (Fig. 3). In the 5-parameter model, in addition to four parameters from previous model, the fifth parameter used to calculate power output is shunt resistance (R_{sh}).
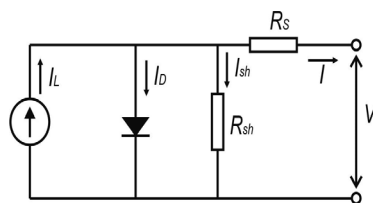

Fig. 3. Equivalent, one-diode circuit
including series of resistance [8]

The current generated in the presented circuit is expressed in equation (4) and more detailed in equation (5), [7].

$$I = I_L - I_D - I_{sh} \tag{4}$$

$$I = I_L + I_o \left(\exp\left[\frac{V + IR_s}{a_T} \right] - 1 \right) - \frac{V + IR_s}{R_{sh}} \tag{5}$$

The power output can be defined by equation [7]:

$$P = VI = V \left(I_L + I_o \left(\exp\left[\frac{V + IR_s}{a_T} \right] - 1 \right) - \frac{V + IR_s}{R_{sh}} \right) \tag{6}$$

Five parameters, used to evaluate the current and voltage in equation (5), are functions of the cell temperature and the solar radiation incident on this cell. Calculation of them is based on parameters obtained from manufacturers, properties of the I–V curve and the derivative of the power at the maximum power point.

Comparison of the 4-parameter and the 5-parameter models carried out in [6] follows that the second model, in contrast to the previous one, is able to calculate the electricity produced by amorphous photovoltaic systems. However, for single crystal and polycrystalline modules, the equations employed in the 5-parameter model reduce to those in the 4-parameter model.

4. Conclusions

Photovoltaic panels are commonly used as integrated systems in new, low energy modern office buildings. However, appropriate design and calculation of their efficiency is very difficult and requires advanced models and simulation techniques. In this paper, the methods implemented in the most popular simulation programs: ESP-r and TRNSYS. Both methods are based on the one-diode equivalent circuit model and correctly predict the power generated by photovoltaic systems.

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