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Design and implementation of a photovoltaic I-V curve tracer: Solar modules characterization under real operating conditions

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ABSTRACT

The performance of a photovoltaic (PV) module depends on real operating conditions such as solar irradiance, ambient temperature, and wind speed, in addition to solar module technologies. To characterize a PV module under these conditions, the measure of the entire current-voltage (I-V) curve in short time requires a suitable data acquisition device. This paper outlines the features of a low-cost acquisition device to characterize a PV module under real operating conditions. It is based on a set of MOSFET IRF540N, and load resistances, an Arduino board, and sensors of current and voltage with high resolution and sampling rate. This system permits to sweep the entire I-V curve by taking a current-voltage point (I, V) within one msec. The effects of operating temperature and solar irradiance on the module performance are investigated. The physical parameters of the module have been extracted by two methods using three solar cell models. The temperature correction coefficients for current, voltage, and efficiency are calculated. The results show a good agreement with those found in the literature.

1. Introduction

The massive global energy consumption and the expected depletion of fossil fuel resources are mainly behind the growing interest in exploring alternative energy sources such as solar energy. Research in the field of photovoltaic energy has grown rapidly over the last three decades relative to various aspects such as modeling, control, and physical extraction parameters [1–5]. The electric output performance of PV modules depend highly on weather conditions [6–10]. These performances are usually evaluated by manufacturers under standard test conditions (STC: operating temperature of 25 °C, irradiance of 1000 W/m^2 and $AM = 1.5$), which are almost never encountered [11,12]. The I-V curve extracted under real operating conditions requires taking the fast variation of climatic conditions into account [11–14]. Thus, in order to reduce the effect of solar irradiance and temperature fluctuations, several techniques are used to automatically measure the I-V characteristic of PV modules. Cotfas et al. [15] used the capacitor charging cycle as an automatic variable load to measure the PV cell I-V curve by about a hundredth of a second. However, fluctuations affecting the obtained I-V curve were observed. Thomas Mambrini [14] developed a technique based on the bipolar transistor to vary the load resistance and acquire 30 points of the PV module I-V characteristic in a relatively long time, 6–8 s. Kuai et al. [16] designed a device based on an electronic load with the linear MOSFET APL501J to cover the complete range of PV panel I-V characteristic but the sampling time and measurement resolution were not indicated. Belmili et al. [17] designed and developed an electronic circuit based on several MOSFET IRFP150N connected in parallel to vary the load resistance and allow the acquisition of PV I-V characteristic, but the sampling time and measurement resolution were not indicated and remarkable fluctuations were observed on the I-V curve. Papageorgas et al. [18] implemented a new method to vary the load resistance by using a MOSFET to measure an I-V curve of 36 points in a time average of 70 ms with visible fluctuations. Tihane et al. [11] used Arduino board and relays to switch between several resistances in order to vary the load resistance and extract the entire PV I-V curve. This solution was based on the use of relays characterized by a long response time. The I-V curve also showed visible fluctuations. In addition, there were several commercial systems to characterize the PV modules, but they were relatively expensive and had a relatively long measuring time [19].

To overcome these problems, an electronic circuit is realized to extract the complete PV I-V curve under different operating conditions. This device is composed of several MOSFET IRF540N controlled by an

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Nomenclature

T	cell/module operating temperature [°C]
PV	photovoltaic
I	solar cell terminal current [A]
V	solar cell output voltage [V]
STC	standard test conditions [T = 25 °C, G_0 = 1000 W/m^2 and AM = 1.5]
α	temperature correction coefficient for current [1/°C]
β	temperature correction coefficient for voltage [1/°C]
δ	correction coefficient for solar radiation
m_S	cells number connected in series
m_P	branches number associated in parallel
T_a	ambient temperature [°C]
G	solar irradiance on module plane [W/m^2]
R_S	series resistance [Ω]
R_{SH}	shunt resistance [Ω]
G_p	parallel conductance [S]
I_{ph}	photo-generated current [A]
R_{SM}	module series resistance [Ω]
R_{SHM}	module shunt resistance [Ω]
G_{pM}	module parallel conductance [S]
I_{phM}	module photo-generated current [A]
I_{SC}	short circuit current [A]
I_0	reverse saturation current [A]
I_{0M}	module reverse saturation current [A]
I_{0i}	reverse saturation current of diode i in conventional model [A]
I_{0iM}	module reverse saturation current of diode i in conventional model [A]
I_{0iaM}	module reverse saturation current of diode i in alternative model [A]
S	module surface [m^2]
$P_{max,\ ref}$	maximum power at SRC [W]
V_M	module output voltage [V]
I_M	module terminal Current [A]
I_{max}	maximum current intensity [A]
V_{OC}	open circuit voltage [V]
V_{max}	voltage at the maximum power point [V]
n	diode ideality factor
n_i	ideality factor of diode i in conventional model
n_{ia}	ideality factor of diode i in alternative model
n_M	module ideality factor
n_{iM}	module ideality factor of diode i in conventional model
n_{iaM}	module ideality factor of diode i in alternative model
a_1, a_2	multiplicative coefficients
I_{Dioa}	total current in the diodes [A]
V_{th}	thermal voltage [V]
R_{TH}	Thevenin's equivalent resistance [Ω]
V_{TH}	Thevenin's equivalent voltage [V]
W_0	main branch of Lambert's function
e	electron charge [$=1.602 \times 10^{-19}$C]
k_B	Boltzmann constant [$=1.3806 \times 10^{-23}$ J/K]
T_{NOCT}	nominal operating cell temperature [°C]
P_{max}	maximum power [W]
η	solar cell electrical efficiency
η_{Tref}	efficiency at reference temperature
β_{ref}	temperature correction coefficient for efficiency [1/°C]
T_{ref}	reference temperature [°C]
γ_1	solar irradiance coefficient
γ	temperature correction coefficient for maximum power [1/°C]
r_{ds}	equivalent on-resistance of MOSFET IRF540N [Ω]
$I_{SC,ref}$	short circuit current at SRC [A]
$V_{OC,ref}$	open circuit voltage at SRC [V]

Arduino board permitting to switch between different load resistance values. The device is also composed of current, voltage, and temperature sensors which are compatible with Arduino board. The obtained I-V curves are exploited to investigate the performance of a PV polycrystalline module. Several extraction methods are proposed in the literature to determine the physical parameters associated with single diode models [3,20], conventional and alternative double diode models [6,21]. Thus, to evaluate the effect of temperature and solar irradiance on the module performance, its physical parameters are extracted. Ortiz-Condé and iterative extraction methods [22,23] are applied here to extract the physical parameters using the three cited models. The results obtained using both extraction methods are compared and are found to be in good agreement with the literature [12,24,25].

2. Materials and methods

2.1. PV modules experimental I-V curve tracer

Fig. 1 and Fig. 2 show respectively the block diagram and the image of the conducted experimental I-V curve tracer for PV modules. The data acquisition process is started by measuring solar irradiance in the PV module plane using the solarimètre – SL200. An implemented

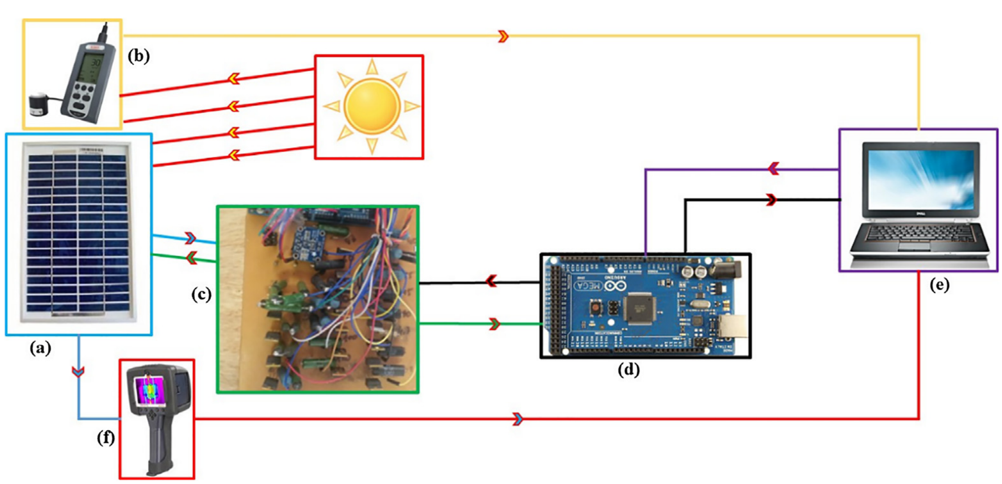

Fig. 1. Block diagram of the PV module I-V curve tracer. (a) PV module, (b) solarimeter -SL200, (c) electronic circuit with sensors, (d) Arduino board, (e) computer.