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Simplified Model for PV Panels Performance Preditcion

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Abstract

In the last years, the growing global energy demand and the even more strictly pollution regulations have led the research to improve efficiency of conventional technologies and to find out innovative solutions to solve these issues. In this scenario, the renewable energy becomes a fundamental resource, especially in the field of electric energy generation. Problems related to non-programmability and effectiveness of renewables can be minimize through the diffusion of distributed generation and energy storage technologies.

In this study, an integrated microgrid, made up of photovoltaic arrays, batteries and a hydrogen generator is presented. The aim of this work is to develop a simplified mathematical model able to describe the behavior of the photovoltaic modules for different operating conditions. On the respect of available literature on this topic, the peculiarity of this model is the possibility of being used simply knowing those parameters usually provided by manufacturers. To validate the model, experimental data recorded during the laboratory tests have been used. Obtained results show that 78 % of the analyzed operating conditions computed using the developed model are within the tolerance range of ± 10 % compared to experimental values.

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Keywords: Photovoltaic; Modellization; Performance Carachterization; MicroGrid

1. Introduction

The increasing of world energy demand, the need to reduce the pollutant emissions and to improve the efficiency conversion of energy systems are crucial issues that must be addressed in a global socio-economic scenario [1]. This

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context have driven the research to focus attention on renewable energy sources. Resources such as solar or wind energy, in addition to avoid pollutant emissions, can be helpful in costs reduction for energy deliver, that could be too onerous otherwise [2]. Despite that, the main issue associate with renewables lies in the non-programmability. This aspect makes difficult the integration of these resources in the electricity grid: non-programmable sources negatively affect the power network stability and reliability, as deeply described in [3-5]. Moreover, the integration of non-programmable resources within the grid force conventional energy systems to work, most of the time, at part load conditions, thus far from maximum efficiency conditions, with high energy production costs. For all of these reasons, optimized management strategies became of fundamental importance to integrate renewables in the power network. One of the most efficient and diffused solutions is represented by Electrical Energy Storage (EES) devices. Storage allows to satisfy the user's energy demand, minimizing the problem related to the non-programmable sources. Indeed, in this way, the user's demand is no longer strictly tied to the availability of non-programmable renewable energy e.g. wind and/or solar [6,7]. For microgrid applications the most widespread devices are the batteries. Another possibility is the chemical storage, such as hydrogen generation. Hydrogen can be generated through water electrolysis, employing renewable energy for the process. The produced hydrogen can be stored into pressurized tanks for later use [8]. The integrated system described in this paper consists of two solar photovoltaic panels (PV) for the exploitation of the renewable non-programmable source, batteries and a hydrogen generator (HG) as storage technologies, power electronics including inverter and converter, a solar charge regulation unit (SCR) and electronic load emulators, both direct (DC) and alternate current (AC), as users. The integrated microgrid is intended to maximize the hydrogen generation starting from a renewable source through the use of batteries to compensate for solar over/under-production. The scope of the study presented is the development of a mathematical model able to describe the behavior of the PV panels, under different operative conditions. Experimental tests, carried out for different ambient operating conditions (i.e. solar radiation values and cells temperature), are used to validate the model. In literature, simulation models based on the knowledge of parameters such as internal resistance, saturation and diode currents, etc., that are hard to estimate without laboratory tests, are deeply described. Examples can be found in [9,10]. Contrarily, the peculiarity of the developed method is that it can be used simply knowing the PV module data commonly provided by the manufacturer (e.g maximum power point current and voltage, open circuit voltage and short circuit current). The strength of this model is the simplicity in its application unless a reduction in the performance prediction accuracy on the respect of more complex modeling approaches.

More in details, the paper is structured as follows: section 2 shows the laboratory integrated microgrid layout. A detailed focuses on PV panels main characteristics is presented. Equations and correlations used in the mathematical model to characterize PV behavior are described in section 3. In section 4 the experimental data results are shown and compared to model results for validation purpose. Finally, conclusions are summarized in section 5.

2. Laboratory integrated microgrid description

The integrated microgrid set-up by the *Energy and the Environment Interdepartmental Centre for Industrial Research, CIRI-EA, of the University of Bologna at Ravenna Technopole*, accommodates the following main components (Fig. 1.):

- two PV panels, parallel connected;
- a power management cabinet including a solar charge regulator unit, two batteries, a DC/DC converter and a DC/AC inverter (24 V/230 V);
- a Hydrogen Generator (HG) equipped with an internal AC/DC rectifier and three hydrogen metal canisters for storage purpose.

The set-up test bench allows to simulate the behavior of a microgrid capable of feeding a load, employing the batteries for non-programmable renewables energy surplus/lack and feeding an electrolyzer for hydrogen generation.

To measure energy fluxes exchanged between components, voltage (ER) and current (IR) measuring sensors are installed in every branch and node, as indicated in Fig. 1. Generated hydrogen mass flow rate (QR) and water quality (LR) are also measured. Finally, through the use of a pyranometer and temperature sensors (TR), the solar radiation (RR) value and the temperature of both ambient and PV cells are recorded.

Main characteristics of the PV polycrystalline modules are listed in Table 1, as specified by manufacturer [11]. The data are provided for standard conditions (STC: Radiation 1000 W/m^2 with a spectrum of AM 1.5 at a cell temperature of 25 °C) and for nominal operating cell temperature (NOCT: Radiation 800 W/m^2, ambient temperature of 20 °C and a nominal operating cell temperature of 48.2 °C).

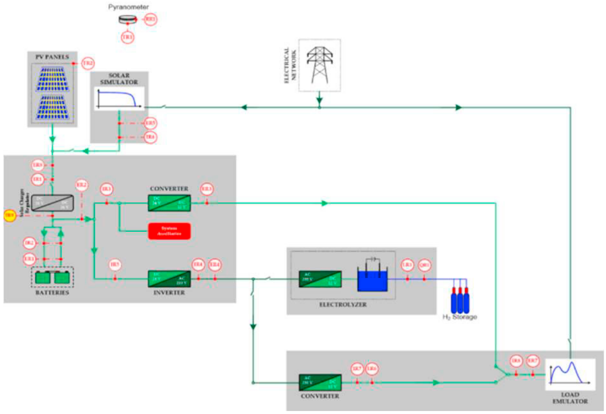

Fig. 1. Schematic layout of the laboratory microgrid with installed sensors.

Table 1. Solar module technical specifications.

DESIGNATION	SPECIFICATION	
Type	Polycrystalline	
	STC	NOCT
Max. power	220 W	155 W
Open circuit voltage (V_{OC})	33.77	30.41
Max. power point voltage (V_{MPP})	27.54 V	23.4 V
Max. power point current (I_{MP})	8.08 A	6.62 A
Short circuit current (I_{SC})	8.62 A	7.02 A
Rated voltage	24 V	
Max. system voltage	1000 V	
Dimensions	990 mm x 1.480 mm x 38 mm	
Weight	19 kg	
Reliability	10 years 90 %, 25 years 80 %	
Quantity	2 units	
Short Circuit Current Temperature coefficient	0.05 %/K	
No-load Voltage Temperature coefficient	- 0.32 %/K	
Performance coefficient	- 0.42%/K	

3. PV mathematical model description

As deeply described in literature [12-14], the performance of a PV module depends on several factors, including the module temperature and the solar radiation [12] values. The behavior of a PV panel can be described with a current-voltage diagram (I-V curve). This curve is characterized by four key parameters: the short circuit current, I_{SC}, the open circuit voltage, V_{OC}, the maximum power point current, $I_{MPP,}$ and the maximum power point voltage, V_{MPP}. In details, I_{SC} increases with higher solar radiation and lower cell temperature values. Instead, the V_{OC} value increases with the increase of solar radiation and cell temperature [15]. This behavior is a general feature of the PV panels, at least for those with conventional silicon technology. The main purpose of this study is to develop a mathematical model able to represent the I-V curve for the panels employed in the laboratory, at different operating conditions. Indeed, derived correlations must account for the influence of the solar radiation and of the cell temperature to realistically represent the behavior of the PV arrays. Equations implemented in the model (Eq.s 1- 4) [16] correlate the voltage value, V as function of current, I, open circuit current, I_{SC}, and max. power point values, I_{MPP} and V_{MPP}. Fig.2. shows the I-V characteristic of the PV module computed through the use of Eq.s 1-4 by means of data provided by manufacturer (see Table 1). To generalize PV behavior at different operating conditions, I_{SC}, V_{OC}, I_{MPP}, V_{MPP} must be evaluated as function of cell temperature and irradiance. It is possible to express these correlations by means of Eqs from 5 to 8 where A, B,…,H are corrective coefficients to be determined, while constant value can be assumed for reference T_{Rif} = 48.2 °C and Irr_{Rif} = 800 W/m^2, $I_{SC,Rif}$, $I_{MPP,Rif}$, $V_{OC,Rif}$ and $V_{MPP,Rif}$ are the currents and voltages values of the PV modules in NOCT condition provided by the manufacturer and presented in Table 1.The coefficients A, C are expressed in [A/ °C], B, D in [A·m^2/W], E, G in [V/ °C] and F, H in [V·m^2/W]. It has to be specified that the corrective coefficients A, B,…,H are considered constant [14]. Their values will be found out through the use of an iterative procedure. The values provided by the manufacturer listed in Table 1 can be used as first attempt values, because they are referred only to the influence of the cell temperature. Then, the remaining coefficients have to be determined.

$$V = \frac{V_{oc}\dfrac{ln\left[k - \left(\frac{I}{I_{sc}}\right)^{N}\right]}{lnk} - R_s(I - I_{sc})}{1 + \dfrac{R_s I_{sc}}{V_{oc}}} \tag{1}$$

where:

$$R_s = \frac{V_{oc} - V_{mp}}{I_{mp}} \tag{2}$$

$$N = \frac{ln(k - k^{a})}{ln\left(\frac{I_{mp}}{I_{sc}}\right)} \tag{3}$$

$$a = \frac{V_{mp}\left(1 + \frac{R_s I_{sc}}{V_{oc}}\right) + R_s\left(I_{mp} - I_{sc}\right)}{V_{oc}} \tag{4}$$

$$\begin{cases} k = 8.08 & I < I_{MPP} \\ k = 2 & I \geq I_{MPP} \end{cases}$$

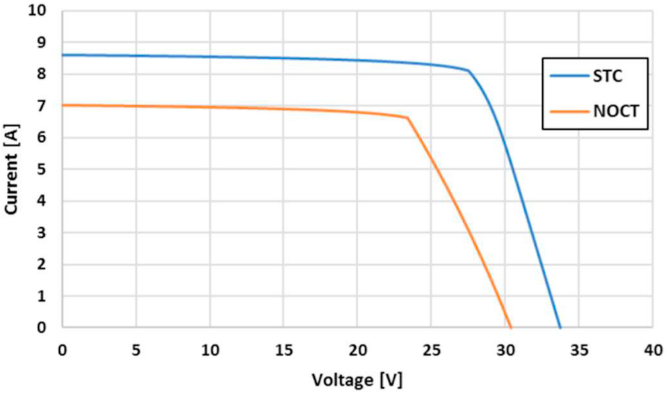

Fig. 2. PV module I-V curve at STC and NOCT conditions.

$$I_{SC} = I_{SC,Rif} + A \cdot \left(T_C - T_{Rif}\right) + B \cdot \left(Irr - Irr_{Rif}\right) \tag{5}$$

$$I_{MPP} = I_{MPP,Rif} + C \cdot \left(T_C - T_{Rif}\right) + D \cdot \left(Irr - Irr_{Rif}\right) \tag{6}$$

$$V_{OC} = V_{OC,Rif} + E \cdot \left(T_C - T_{Rif}\right) + F \cdot \left(Irr - Irr_{Rif}\right) \tag{7}$$

$$V_{MPP} = V_{MPP,Rif} + G \cdot \left(T_C - T_{Rif}\right) + H \cdot \left(Irr - Irr_{Rif}\right) \tag{8}$$

4. PV model tuning and validation

In order to tune the mathematical model, extrapolating the corrective coefficients of Eq.s 5-8, experimental data have been used, acquired during different ambient and PV panels operating conditions. Fig. 3. shows in a cohesive way the experimental data distribution used as function of the solar radiation and cell temperature (T_C) values. The number of recorded data corresponds to about 33 hours of laboratory tests. Analyzing the data, the observed minimum and maximum values of the irradiance are respectively 79 W/m^2 and 964 W/m^2 while, for the cell temperature, are 12 °C and 52 °C.

Dividing the data into groups, according to value of irradiance and cell temperature, the influence of these parameters on the I_{SC}, V_{OC}, I_{MPP} and V_{MPP} can be determined. To determine the value of the coefficients A, B,…,H the method of least squares has been employed. Applied method allows to compare the experimental data with the ones computed through Eq.s 1-4. Through an iterative procedure, it is possible to find out values of I_{SC}, V_{OC}, I_{MPP} and V_{MPP} that minimize the difference between experimental and computed data values. This operation is repeated for each data group previously identified. Finally, comparing the results of each group, it is possible to find out the corrective coefficient A, B,…,H, that define the dependence between I_{SC}, V_{OC}, I_{MPP} and V_{MPP} and irradiance and cell temperature Obtained values from model tuning are shown in Table 2.

To verify the accuracy of the proposed method, with the introduction of the corrective coefficients presented above, a comparison between the experimental values and the ones computed has been carried out. In details, employing the experimental values of irradiance, cell temperature and current of the PV module the corresponding voltage has been evaluated using Eq.s 1–4.

Validation results show that the 78 % of the computed values are within the tolerance range of ± 10 % than the experimental values. Fig.4. shows the comparison between the I-V curve computed through the use of the developed model and the experimental data. The I-V curves have been plotted considering average values of irradiance and cell temperature of the considered experimental data. In detail, Fig.4a.with Irr = 800 W/m^2 and T_C = 30 °C; Fig.4b.with Irr = 600 W/m^2 and T_C = 27 °C. To improve the accuracy of the mathematical model, future steps of the study will be to consider the corrective coefficients A, B,…,H no longer as constants but as function of both irradiance and cell temperature.

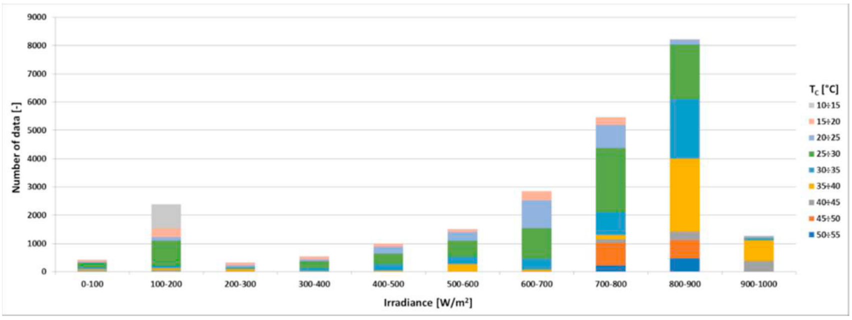

Fig. 3. Distribution of experimental data used to tune the mathematical model.

Table 2. Values of the corrective coefficients.

I_{SC}	A	B
	0.0035	0.0083
I_{MPP}	C	D
	0.0033	0.0078
V_{OC}	E	F
	-0.1291	0.0018
V_{MPP}	G	H
	-0.046	0.0154

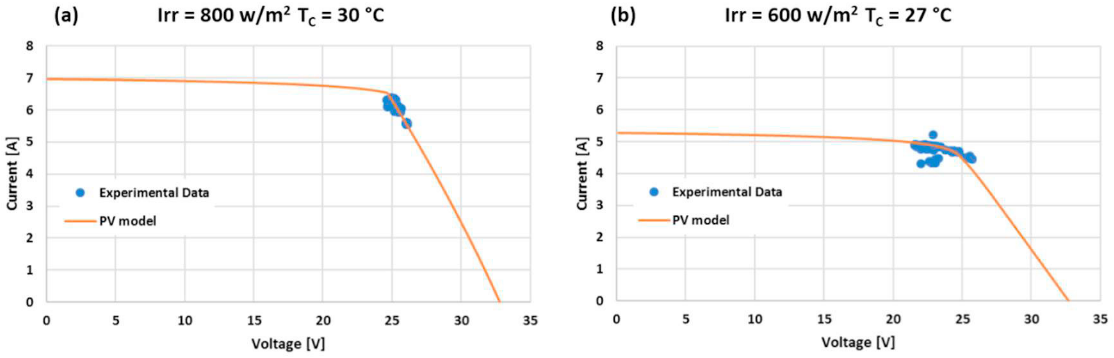

Fig. 4. Comparison between developed model and experimental data with: a) Irr = 800 W/m^2 and T_C = 30 °C; b) Irr = 600 W/m^2 and T_C = 27 °C.

5. Conclusions

The purpose of this study is develop and validate a simplified mathematical method able to simulate the behaviour of PV modules employed in an integrated microgrid. The proposed method has been tuned using experimental data recorded during several laboratory tests. A comparison between the experimental values and the computed ones shows that the 78 % of them results within the tolerance range of ± 10 % than the experimental value. This reduction in accuracy on the respect of PV simulation models available in literature is due to the proposed approach, which is exclusively based on the use of the information provided by PV panels manufacturers.

Nomenclature

AM	Air Mass
HG	Hydrogen Generator
I_{SC}	Short circuit current [A]
I_{MPP}	Maximum power point current [A]
I_{rr}	Solar radiation [W/m^2]
NOCT	Nominal operating cell temperature
PV	Photovoltaic
STC	Standard test condition
T	Temperature [°C]
V_{MPP}	Maximum power point voltage [V]
V_{OC}	Open circuit voltage [V]

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