Investigation of different simulation tools for solar photovoltaic modules

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Abstract

Renewable energy resources will be an increasingly important part of power generation in the new millennium. Besides assisting in the reduction of the emission of greenhouse gases, they add the much-needed flexibility to the energy resource mix by decreasing the dependence on fossil fuels. Furthermore, as many international studies have already demonstrated, the use of photovoltaic is a crucial point to achieve the Net Zero Energy Building (nZEB) standard. In order to allow the designers to count on the renewable energy resources to compensate the energy needed, an easy and reliable tool is necessary, besides the building energy simulation tools. This paper aims to present a comparison between different simulation tools, in order to underline differences and similarities rather besides comparing the numerical responses.

Several parameters related to the PV panels will be discussed in order to compute their influence on each numerical model. Further investigations of this preliminary study will be done in order to analyse the PV models in order to find the best way to simulate and to model building integrate photovoltaic element (BIPV).

1. Introduction

Simulation modelling has become an important part of our world and it is used very often to predict different energy scenarios and to evaluate the cost-effectiveness of a particular solution. Simulation is also widely used to optimize new technologies and to investigate their behaviour in different context and configuration. Recent advances in simulation methodologies, availability of software, and technical developments have made simulation one of the most widely used and accepted tools in system analysis and operation research.

Simulation tools are also used in the design phase of Photovoltaic systems. They are very important because this is the phase where the client decides if the Photovoltaic system is cost-effective and economically attractive or not.

For this reason in the last decade different tools have been developed both by PV industries and by Research institutes in order to help planners work. Mitchel et al 2009, identified 13 different types of software (RETScreen, NREL Solar Advisor, ESP-r, SolarGIS, INSEL, SolarDesign, PV F-Chart, PVSYST, TRNSYS, SolarPro, PV DesignPro-G, PV Sol, PV Sol Expert) but many others are available such as DDS-CAD, Polysun, Valentin Software, SolarNexus.

Within this work, the authors investigate the capability of three simulation tool for the modelling of photovoltaic (PV) system and how they can be improved to simulate building integrated photovoltaic elements: PVSYST as the worldwide known software for PV-system simulation, TRNSYS and ESP-r as worldwide used software for Building energy simulations.

2. Method

In order to compare the capabilities of the three software packages to simulate the PV-system production and its interaction with the building envelope, a simulation analysis was done for a building integrated photovoltaic (BIPV) system installed on a tilted roof of a low energy house in Bergamo. The city lies 249 m above sea level, with a latitude of 45.70°N and a longitude of 9.67°E. The annual total solar radiation in Bergamo is

1,398 kWh/m2 with approximately 1,900 hours of sunshine.

Table 1 summarizes the technical specification of the considered PV panel.In all the performed simulations the model proposed by Perez was used (Perez 1988) to model the sky conditions and the radiation distribution of the tilted surface.

ELECTRICAL DATA		
Measured at Standard Test Conditions (STC): Irradiance 1000W/m², AM 1.5, and cell temperature 25° C		
Nominal Power (+5/-0%)	P_{nom}	333 W
Cell Efficiency	η	22.9 %
Panel Efficiency	η	20.4 %
Rated Voltage	V_{mpp}	54.7 V
Rated Current	I_{mpp}	6.09 A
Open-Circuit Voltage	V_{oc}	65.3 V
Short-Circuit Current	I_{sc}	6.46 A
Maximum System Voltage	IEC	1000 V
Temperature Coefficients	Power (P)	– 0.38 %/K
	Voltage (V_{oc})	– 176.6 mV/K
	Current (I_{sc})	3.5 mA /K
NOCT	45° C +/– 2° C	
Measured at Nominal Operating Cell Temperature (NOCT): Irradiance 800W/m2, 20° C, wind 1 m/s		
Nominal Power	P_{nom}	247 W
Rated Voltage	V_{mpp}	50.4 V
Rated Current	I_{mpp}	4.91 A
Open-Circuit Voltage	V_{oc}	61.2 V
Short-Circuit Voltage	I_{sc}	5.22 A
Number of cells connected in series in module		96
Individual module area (A)		1.63 m2

Table 1 – Technical specification of the PV panel

3. Description of the three tools

3.1 TRaNsient SYstems Simulation (TRNSYS)

TRNSYS is a commercially available simulation program, evolved in 1975. This software is the outcome of an international collaboration between the United States, France, and Germany. TRNSYS alleviates the accession of mathematical models, the potentialities of the multi-zone building model, the usable add-on components, able to port with other simulation programs. It is one of the most pliable energy simulation software packages.

The main components used in the TRNSYS numerical simulation are based on mathematical models written in FORTRAN and are:

- type 56b: This component models the thermal behaviour of a building divided into different thermal zones; it is useful to include thermal behaviour of BiPV modules;
- type 194: Photovoltaic array. This component determines the electrical performance of a photovoltaic array. The model is based on the calculation method presented by DeSoto et al 2005 . Type 194 has been used in simulations involving utility grid connections. The model determines the current and power of the array at a specified voltage. Other outputs include current and voltage at the maximum power point.
- type 15: Weather Data Processor. This component reads and interprets weather data available in a series of standardized formats. In particular in the model implemented was used a Typical Meteorological Year version 2 (TMY2) format created with Meteonorm.

The model used in type 194 is based on the five-parameter equivalent circuit model that is presented in Duffie and Beckman 1999. The main thrust of this model is to reliably extrapolate performance information provided by the manufacturer at standard rating conditions (1000 W/m2, 25 °C, 1.5 AM) to other operating conditions. The model, as described by De Soto et al. 2005, is based on the equivalent circuit diagram shown in Figure 2.

In particular the five parameters used to model the PV cell were calculated by an engineering equation-solver application which calculates the 5 parameters required to characterize the energy conversion from PV modules, according to the model developed by DeSoto et al 2005.

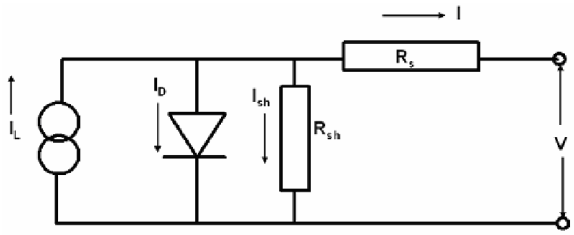

Fig. 1 – Equivalent electrical circuit

3.2 PVSYST

PVSYST (Mermoud, 1995) is a photovoltaic system analysis software program developed by the Energy Group at the University of Geneva in Switzerland and can be used at any location that has meteorological and solar insolation data. It is widely used due to the many parameters available for the user to modify. It is a PC software for the study, sizing, simulation and data analysis of complete PV systems. It is suitable for grid-connected, stand-alone, pumping and DC-grid (public transport) systems, and offers an extensive meteorological and PV-components database.

For POA (plan of array) radiation, the default is the model described in Hay 1979, however the user can also specify the Perez model (Perez et al. 1987). PVSYST uses the one-diode equivalent circuit model for calculating performance in cSi (crystalline silicon) and HIT (hetero-junction intrinsic thin layer) modules, and a modified version for what they consider "stabilized" thin film modules, such as aSi (amorphous silicon), CiS (copper-indium (di)selenide or copper-indium gallium (di)selenide technologies) and CdTe (cadmium telluride).

The five parameters required by the model are defined, also in this case, from the engineering equations that govern the electrical process starting from standard conditions. Since this procedure may lead to solutions without physical meaning, just three of the equations are considered and an explicit choice of the resistance (Rs) parameter is directly performed by the user by means of a graphical interface. In the cases in which an experimental measurement of the complete I/V characteristic is available, the definition of the Rs parameter is defined minimizing the error between experimental data and model results (PVSYST User Guide 2012).

3.3 ESP-R

ESP-r is an integrated modelling tool for the simulation of the thermal, visual and acoustic performance of buildings and the assessment of the energy use and gaseous emissions associated with the environmental control systems and constructional materials. In undertaking its assessments, the system is equipped to model heat, air, moisture and electrical power flows at user determined resolutions.

The model in ESP-r actually comprises two models: a simple one based on a constant efficiency, and a more elaborate one based on an equivalent one-diode model.

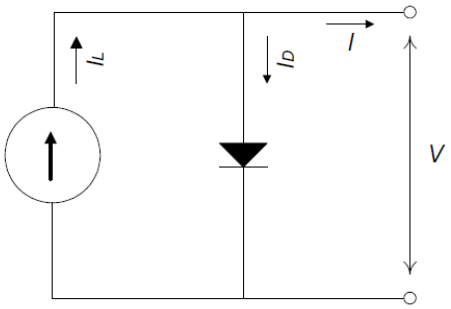

Fig. 2 – One diode model implemented in ESP-r

The current-voltage (I-V) characteristic of a solar cell can be obtained by considering an equivalent circuit of cell (Markvart 2000). This is known as the equivalent one-diode circuit and is illustrated in Fig. 2. The output current, I, is equal to the difference between light-generated current and the

diode current.

The data input requirements for the model are:

1. Open circuit voltage at reference conditions (V).
2. Short circuit current at reference conditions (Amps).
3. Voltage at maximum power point at reference.
4. Conditions (V).
5. Current at maximum power point at reference conditions (Amps).
6. Reference insolation (W/m2).
7. Reference temperature (K).
8. Number of series connected cells (not panels) (-).
9. Number of parallel connected branches (-).
10. Number of panels in surface (-).

To support PV-integrated building simulation and enable heat and power utilisation studies, the PV model has been implemented within the ESP-r system as active material. This guarantees a special behaviour to multi-layered construction nodes in order that they can transform some part of their absorbed solar energy to electricity according to the previously described mathematical modeland the use of an electrical power flow network to allow the modelling of local electricity use and co-operative switching with the grid.

4. Simulation results

The aim of this paper is to compare the results of the three simulations. The power of the system and as a consequence the energy output is investigated. Further analysis has to be done to check the thermal characteristic of the BiPV modules.

The 10kWp BiPV system is installed on a tilted roof. The 30 high efficiency modules lies on the roof plane which it is tilted of 15° and with an Azimuth of 45° West (see Fig. 3).

The thermal characteristics of the building are reported in Table 2.

In order to understand the results of the three simulations, only two characteristic weeks' results are plotted (Fig. 4, Fig. 5): typical summer week and typical winter week.

Fig. 6 shows the predicted power generation of the BiPV array, respectively for a typical summer and winter week.

Looking at the results a good fit is observable between the three solutions. Some small differences (smaller than 11%) can be seen just near to the peak values (this is due to the predominance of the direct irradiance). This consideration may lead to conclude that the differences, even though small, in energy production are also influenced by

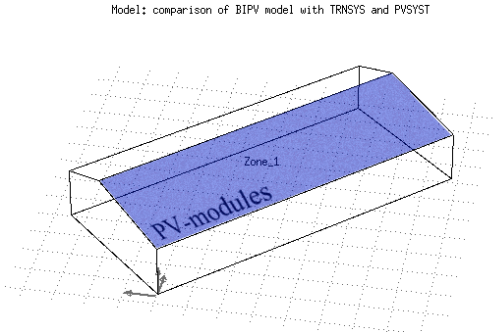

Fig. 3 – The picture shows the simulated model. It is one Zone model with a tilted roof.

	U-VALUE [W/m²K]	Boundary
Roof	0.33	External
BiPV Roof	0.33	External
External wall	0.2	External
Partition	1.3	Adiabatic

Table 2 – Construction specifications

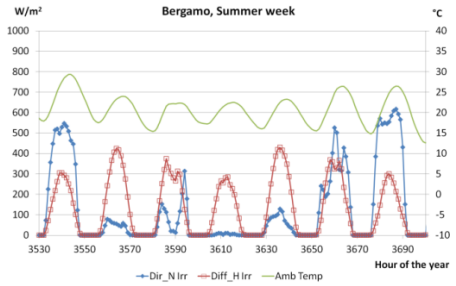

Fig. 4 – Typical Summer Week in Bergamo (ITA).

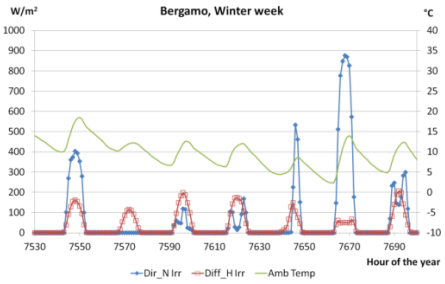

Fig. 5 – Typical Winter Week in Bergamo (ITA).

thermal models of the PV panel and not only from the definition of electrical parameters. Considering the whole year the total energy yield differences is about 5% between ESP-r and PVSYST and -11% between TRNSYS and PVSYST.

5. Conclusion

The simulation results using the one diode models implemented in TRNSYS, PVSYST and ESPr are comparable. The three resulting energy curves have similar shapes both in winter and in summer. However, if we consider the PVSYST result as a benchmark, the TRNSYS model seems to underestimate the energy production during the seasons and the ESP-r model over-predict the amount of power generated at midday, especially on sunny days.

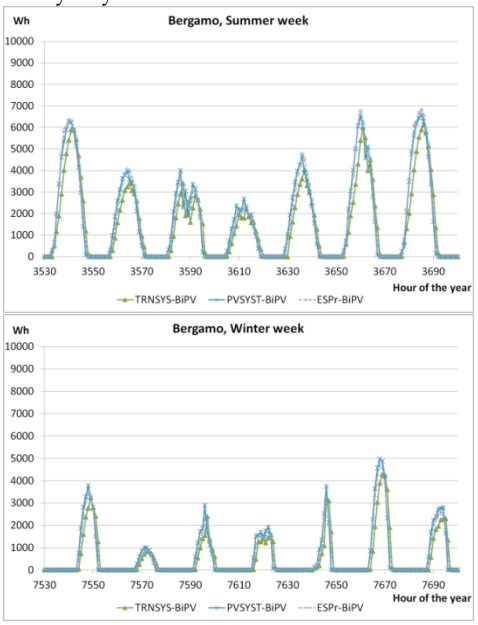

Fig. 6 – Left picture: power generation of the array predicted by the three simulation tools in a typical summer week. Right picture: power generation of the array predicted by the three simulation tools in a typical winter week.

6. Discussion

Modelling building-integrated photovoltaics (PV) in building energy simulation tools presents many challenges. For example, photovoltaics respond to many environmental influences, such as irradiance, temperature, wind speed, angle of incidence of solar rays, and spectral distribution of irradiance. Furthermore, PV modules are susceptible to shading from one part of the building onto the module.

In addition, parameters characterizing PV modules are often hard to obtain. Manufacturer's data often provide relatively easy access to parameters such as open circuit voltage, short circuit current, and nominal efficiency under standard test conditions (1000 W/m², 25 °C, air mass 1.5). But representing accurately the electrical characteristics of the modules from such a small set of parameters, and under a wide range of environmental conditions, is challenging.

Fig. 7: Roofs and facade installation monitoring campaign are now ongoing at ISAAC-SUPSI to validate the tools prediction.

Finally, most PV simulations programs are chiefly interested in the power output of the module. By contrast, tools for energy simulation in buildings require additional outputs such as light reflected

by the modules and transmitted through it, and radiative, convective and conductive heat transfer at the front and the back of the PV array.

The author of this paper started to analyse the differences between the state of the art tools in order to identify a possible amelioration of the model.

A monitoring campaign is also needed in order to validate the present tools and to improve them. This is what is currently ongoing at the Institute for Applied Sustainability to the Built Environment (ISAAC-SUPSI). Different roof integrated BiPV modules and facade integrated PV systems are currently under investigation and the achieved result will be presented in a further research paper.

7. Nomenclature

Symbols

Amb	Ambient
BiPV	Building Integrated Photovoltaic
Diff_H	Horizontal Diffuse irradiation [W/m^2]
Dir_N	Normal Direct irradiation [W/m^2]
PV	Photovoltaics
Temp	Temperature [°C]

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TRNSYS documentation is available online at http://sel.me.wisc.edu/trnsys/

ESP-R documentation is available online at: http://www.esru.strath.ac.uk/Programs/ESP-r.htm

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