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ANALYSIS OF THE PV SYSTEM PERFORMANCE THROUGH SIMULATION: A CASE STUDY

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Photovoltaic technology is the future of the energy source and represents a clean energy, which does not pollute the environment and it has been developed faster than others technologies, during the past years all over the world. Presently the photovoltaic panels (PV) system is mainly used in buildings for electricity.

The aim of this paper is to analyze the dynamic behavior of grid-conected PV energy production for a system that is integrated on the roof of a building. For this analyze, the PVsist software package was used. This software offers the possibility to analyze the energy production, taking into account the energy losses from the PV system during one year. Moreover, the system was validated and simulated under Matlab/Simulink environment.

Keywords: Renewable energy, photovoltaic panels, system, simulation

1. Introduction

Presently, the global electricity consumption has increased at the high rate in recent years, and in the further will continue to increase due to growth in population. Buildings present a high-energy consumption and they are largely responsible for the emissions of greenhouse gases. To reduce this worrying rise, it is necessary to find a way to deploy more renewable energy sources [1]. The photovoltaic panels are ready to be integrated in the surface of building or placed in the neighborhoods as solar farms. These sources of energy are becoming today an important potential in the energetic sector and economic development for grid-connected PV system or other application for PV models [9].

A recent taken by the European Union imposes to, member states a reduction in energy consumption from primary energy with 20%, and an increase in renewable energy with 20% while reducing the greenhouse gas emission with20% by the end of the year 2020 [2,3]. Romania has fulfilled one of the requests imposed by the European Union by growing renewable energy with 20 %.

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The total energy consumption in the Europe Union in 2014 was 3226 TWh and the electricity production was 3732 TWh. In Romania, the electricity consumption was 44 TWh and represents 1% of the total energy consumed in Europe, while, the electricity production was 64 TWh representing 2% of the total energy production at European level. Moreover, in 2014 the European Union has 30% of the electricity production coming from renewable sources, which, Romania has a contribution of 9.6% consisting of wind and solar.

According to the Romanian PV Market: Outlook 2014-2025 [4], Romania is one of the most promising markets for photovoltaic energy investments in South-East Europe, with green certificates to support scheme. The green certificates may be traded within a minimum value of 27 €/MWh and a maximum value of 55 €/MWh. By the end of 2013 Romania had a capacity of photovoltaic (PV) installed of 1000 MWp (1 GWp) [4]. In the future, an increase of PV system installed is expected.

In this article, we present a study of the energy production of a PV system integrated in a passive house and which is connected to the local network of the University Politehnica of Bucharest. Additionally, we performed simulation using PVsyst of the PV system connected to grid to see the efficiency of photovoltaic panels, then the results of the simulation were compared to the actual data.

2. PV system description

The PV system installed on the roof of the passive house that is located in University campus, is made of Si polycrystalline solar cells with an efficiency of 13.4% having a nominal power of 225 W/PV, a surface area of 1.67 m^2 /PV, and a total area of 22 m^2 for the 13 panels. These PV modules were connected to an inverter which is designed to transform direct current (DC) into alternative current (AC). The inverter has a nominal power of 3 kW, operating voltage at 120-580 V and a frequency between 50 and 60 Hz. A very important aspect of the PV system operation and especially how much energy the system can produce, is represented by the orientation of panels and the angle at they are placed. Our PV system was placed at 15° angle, i.e. the same angle as the roof, and it was oriented to the South.

On the roof, there were installed a sensor to measure the outside temperature and a pyrometer that measures the solar radiation that falls on the surface of the PV module. Climate condition represents an important role in the energy delivered from photovoltaic panels. In Bucharest, summers are very hot with temperatures up to 40 °C and the temperature drops down in winter to -15 °C.

PV array has the output characteristics that depend on the cell temperature, solar radiation, output voltage and current [8-10]. The solar cell has basically a semiconductor with p-n junction, which depends on the solar radiation to generate current using the photovoltaic effect [6]. Solar cells are grouped in series and parallel in photovoltaic panels (as in Fig. 1).

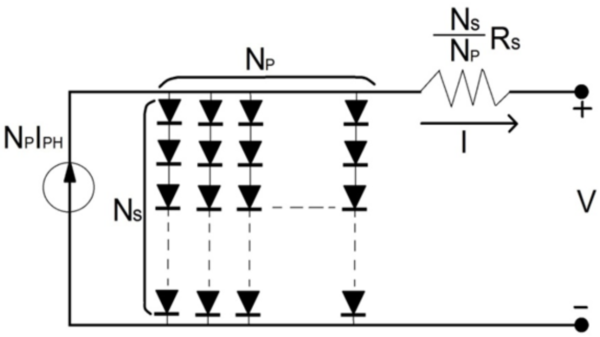

Fig. 1. Solar cells arrangement and electrical connection in one panel [5]

The model that predicts the power production of PV array and the relationship of current-voltage can be defined in the following equations (1-7) [5]:

$$I = I_{PH} - I_S \left[e^{q\left(\frac{V + I_{RS}}{k \cdot T_C \cdot A}\right)} - 1 \right] - \frac{V + I_{RS}}{R_{SH}} \tag{1}$$

$$V = N_s \cdot \frac{k \cdot T}{q} \tag{2}$$

$$I_{PH} = (I_{SC_{STC}} + (K_i \cdot \Delta T)) \cdot \frac{G}{G_{STC}} \tag{3}$$

$$\Delta T = T_C - T_{STC} \tag{4}$$

$$I_S = I_{RS} \cdot \left(\frac{T_C}{T_{STC}}\right)^3 \cdot e^{\left[q \cdot E_G \cdot \left(\frac{\frac{1}{T_{STC}} - \frac{1}{T_C}}{k \cdot A} \right) \right]} \tag{5}$$

$$I = N_P \cdot I_{PH} - N_P \cdot I_S \left[e^{\left(\frac{q\left(\frac{V}{N_S} + \frac{I_{RS}}{N_P}\right)}{k \cdot T_C \cdot A} \right)} - 1 \right] - \frac{\frac{N_P \cdot V}{N_S} + I_{RS}}{R_{SH}} \tag{6}$$

$$I_{RS} = \frac{I_{SC}}{e^{\left(\frac{q \cdot V_{OC}}{N_S \cdot k \cdot A \cdot T_C}\right)} - 1} \tag{7}$$

where:
I_{PH} - *Light-generated current (photocurrent), [A]*
I_S - *Cell saturation current at the dark current, [A]*
Rs - Series resistance, [Ω]
A - Ideal factor for Si-polycrystalline is 1.3;
R_{SH}- *shunt resistance, [Ω]*
V - Thermal voltage of PV module, [V]
N_S - *Number of the cell connected in series;*
q = $1.60217646 \cdot 10^{-19}$ *[C], is the electron charge;*
k = $1.3806503 \cdot 10^{-23}$ *[J/K], is the Boltzmann constant;*
T - Temperature of the p-n junction, [K]
$I_{SC_{STC}}$ - *cell short-current at STC (Standard Test Conditions, [A]*
Ki - short circuit current coefficient (this value is available from manufacturer PV)
T_{STC} *= 25° [C]*
G - Surface irradiance of the cell, [W/m^2*]*
T_C - *cell working temperature, [K]*
E_G - *Band-gap energy at semiconductor (in our case the band-gap Si is 1.1 eV).*
I_{RS} - *Cell reverse saturation current at standard test conditions temperature and solar radiation*

Using all eight (1-8) equations in Matlab/Simulink, the charts presented in Figs. 2-5 were obtained. These results describe the P-V and V-I characteristics of the PV model. A very important element of the photovoltaic model is the maximum power point. The V-I curve describe that the PV operates at the parameters described in the technical data of the photovoltaic panel. If photovoltaic cells operate around the maximum power point, this means that the PV operates at the maximum efficiency.

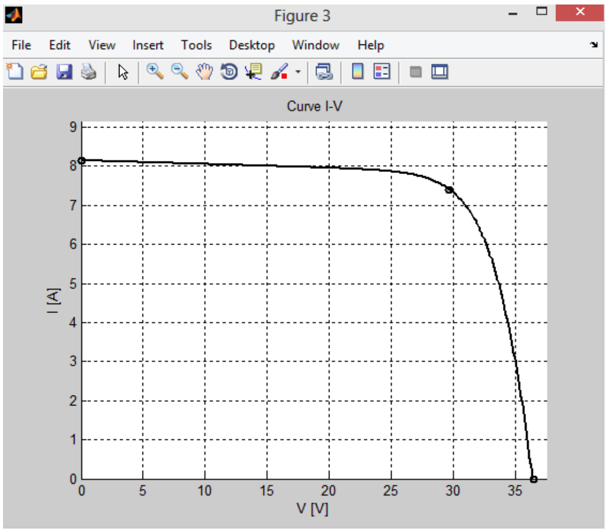

Fig. 2. The I-V curve for PV Schott_Solar model.

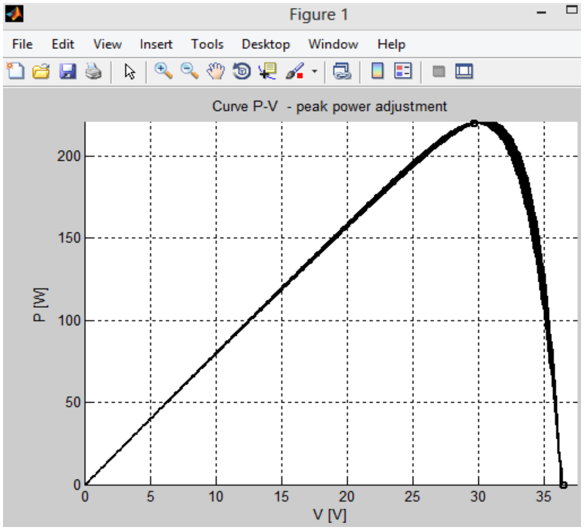

Fig. 3. The P-V curve for PV Schott_Solar model.

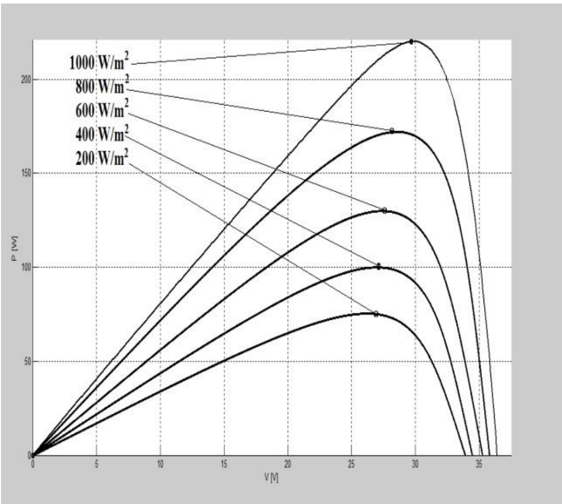

Fig.4. P-V output characteristics at different solar radiation

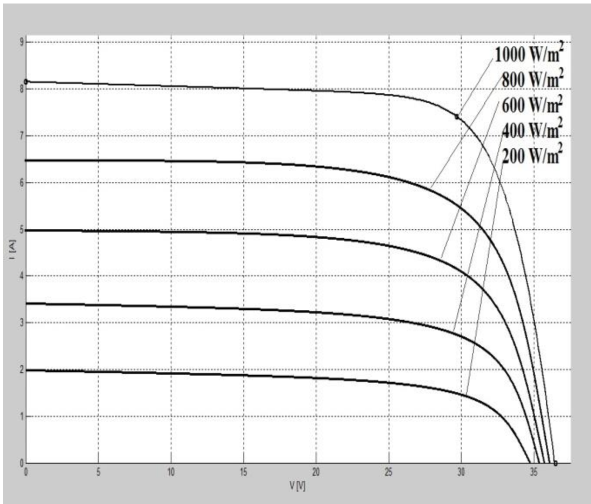

Fig. 5. I-V output characteristics at different solar radiation.

For a better understanding of how a photovoltaic panel works, a schematic illustration of the model analyzed was performed in Matlab/Simulink (Fig. 6).

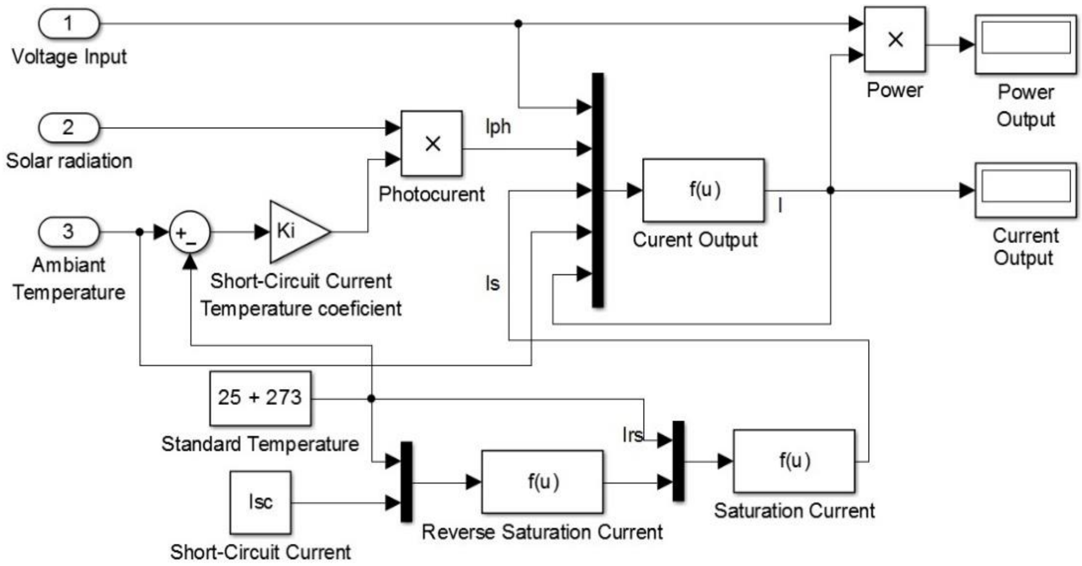

Fig. 6. Schematic illustration of the PV electricity module working, drawn using Matlab/Simulink

3. PVsyst simulation Tools

PVsyst program was used to predict the energy estimated from grid-connection project that is based on installation and operating cost of the system design parameters specified as inputs for the PV system [7]. This program includes a detailed contextual guideline that explain in detail procedures and models used and offers an economic approach and a guide in the development of a project. We can import in program a meteo data from other sources, or personal data. Menu of this program includes the following activities: to simulate full design of remote PV systems; full design of PV system connected to the grid; complet database of PV panels, inverters, meteorological data; Useful 3D application to simulate near shadings; import irradiation data from PVGIS, NASA databases; economic evaluation and payback; export the calculation to CVS files, etc. [7]. To have a correct simulation of PV system we must take into account the climatic factors. For our simulation, the climate data were taken from Meteonorm program.

3.1. Result of the simulation

The PV system connected to the grid, used as model in our simulation, was simulated under environmental condition PVsyst has many interfaces application for users, distributed in numerous areas according to a specific project area. The project area can be described as many inputs data including various parameters which define the simulation system design under operational conditions.

The simulation begins with the specification of parameters of PV system, climatic data, specified the location. PVsyst calculates for every simulation the hour global irradiation, the output of energy of the PV module, the angle of surface, the orientation of PV model with the sun. I, also, calculates the energy transformed from DC to AC to determine the amount of energy that was taken or delivered to the electrical grid. The software can give details on hourly, daily, monthly and yearly basis for the simulation. The data resulted using this program are available graphically or in a table format. Moreover, the program can offer an economic analysis that takes in consideration the investment cost, financial benefits or the life time of project.

The current simulation represents an example of the PV system project that is based on the software run with a specific data Bucharest/Romania in terms of climate specification. In this simulation, the PV system was oriented to the South and placed at an angle of 15° as shown in Fig. 7.

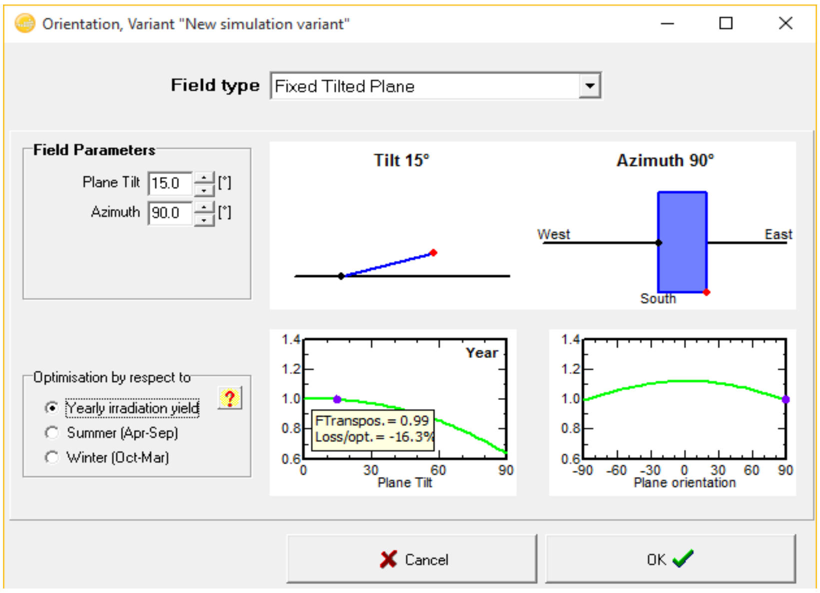

Fig. 7. First specification of PV system.

Next step in the simulation was to introduce all the specification from technical data of PV system such as: reference conditions of solar radiation; (1000 W/m2); short-circuit current (ISC= 8.24 A); maximum of power point (Impp = 7.69 A); temperature at standard test condition (T=25° C); open circuit (Voc = 36.70 V); voltage (Vmpp = 29.30 V); number of cells of PV/module = 60 solar cells put in series and efficiency of PV model, which is 13.47%. To better describe the characteristics of PV module, the simulation software defined the current and voltage curve as presented in the Fig. 8. Additionally, the simulation can offer specification about inverter that transform the power DC into AC, and the efficiency of the inverter at different potentials (i.e. Fig. 9). After all the data, were introduced the final step consists in running the simulation. The results are presented in Figs. 10-14 and in table 1. The main of the simulation result give access to the complementary table and graphs for a comprehensive analysis of the simulation reports.

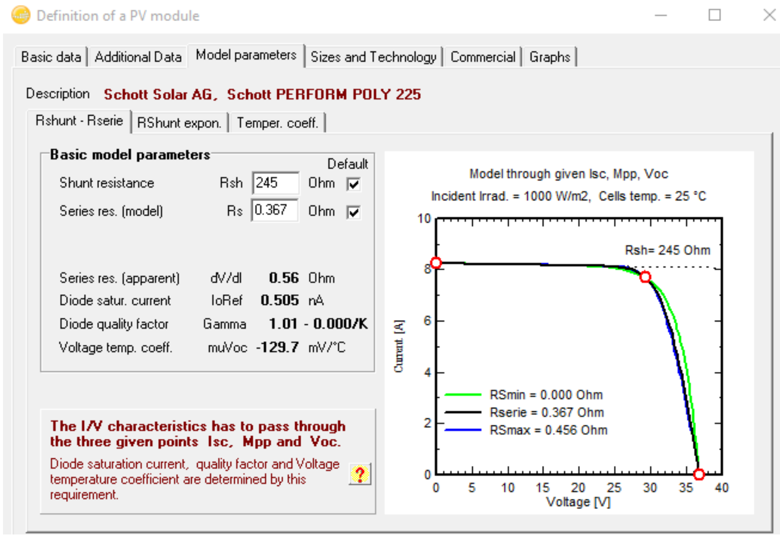

Fig. 8. Current and voltage characteristic of PV model.

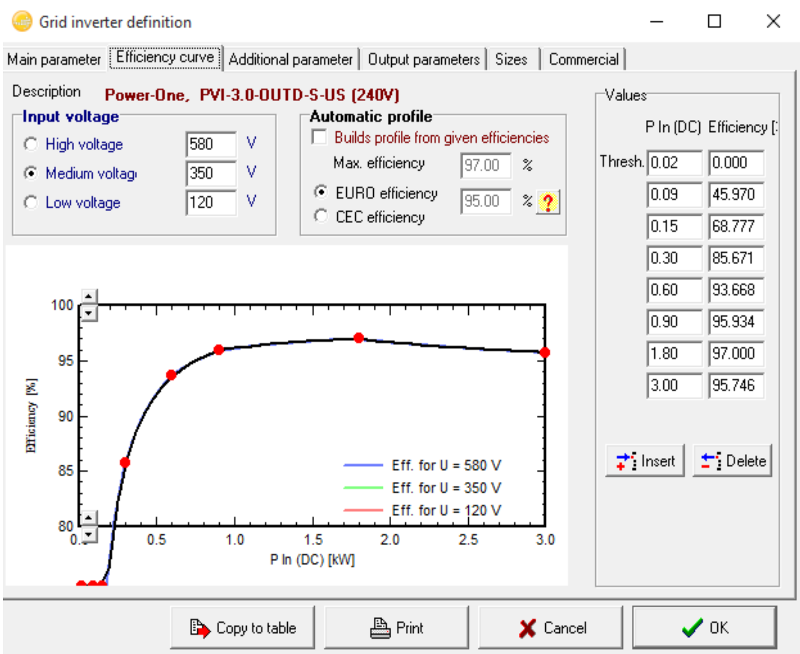

Fig. 9. Representation of Invertor characteristic.

Fig. 10 is presented the Input and Output diagram which gives detailed information about the general specification of the PV system and represent the simulation of every day of the energy that was injected into the grid in the correlation with the global incident irradiation over the photovoltaic panels.

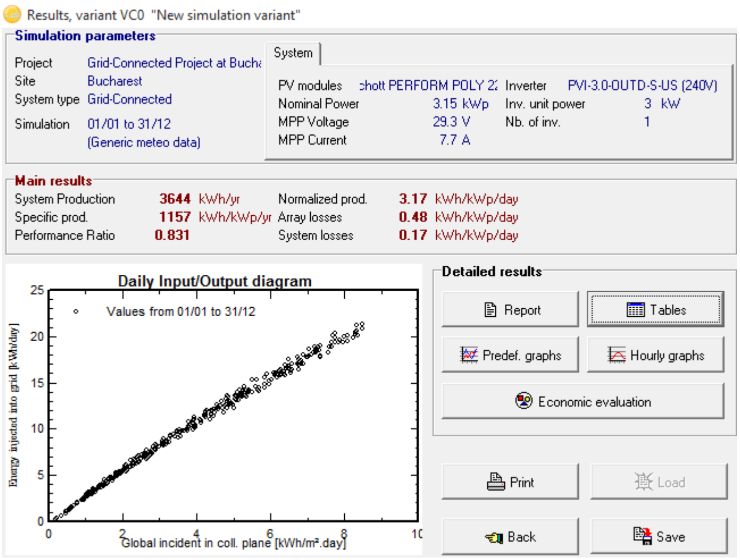

Fig. 10. The daily input output diagram of energy injected into grid and global incident irradiation

It can be seen the data in this graphic consist of points that are in a straight line. There is a small dispersion of points that could be explained by a high irradiation hitting the panel surface, resulting an increase of the energy delivered of PV system.

Fig. 11 represents the PV system power output distribution during one year in correlation with the solar irradiation.

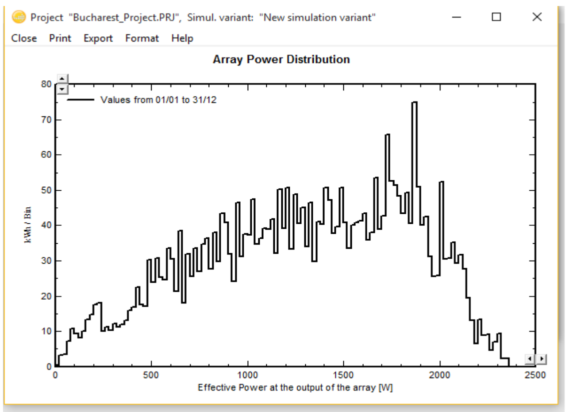

Fig. 11. Simulation the energy output of PV system during one year.

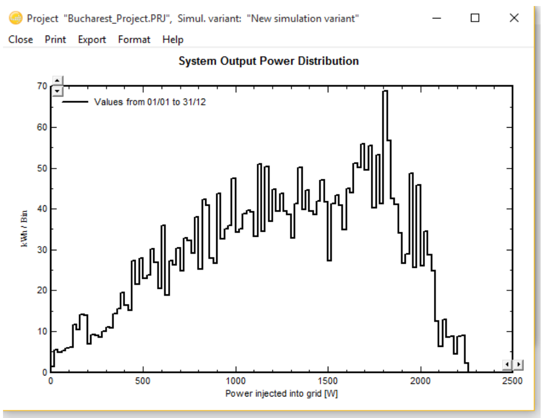

Fig. 12. Simulation the energy delivered into the grid during one year.

It can be observed from both Fig. 11 and Fig. 12, that the energy delivered by the PV system are the same, i.e. there are not significant differences between the two graphs, which can be explain by the fact that PV system has small energy losses.

The PV system losses can be observed much better in Fig. 10, which represented the energy delivered by the PV system in each month. Energy losses given by photovoltaic panels represent 0.48 kWh/kWp/day, inverter loss is 0.17 kWh/kWp/day and the produced energy inverter output was 3.16 kWh/kWp/day.

In Fig. 13 the efficiency of PV system corresponding each month in part is shown, in correlation with the power production. It can be seen that the PV efficiency remains between 12 % and 13%. Also it can be noted that the PV power delivered in summer months increases, but the efficiency decreases in the months of May to August. This can be explained by the fact that the solar cells lose energy through heat. That part of energy of solar cells is actually consumed by cells instead of producing energy.

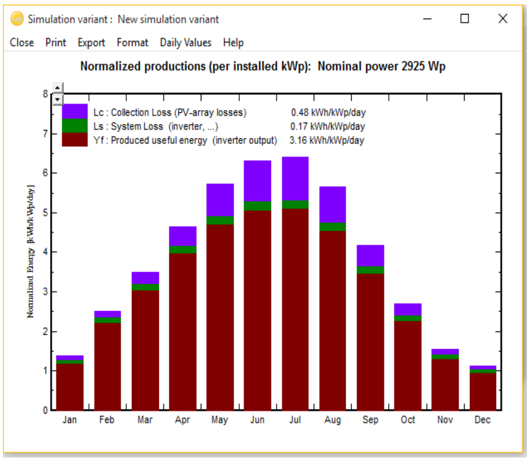

Fig. 13. Energy delivered of the PV system in every month.

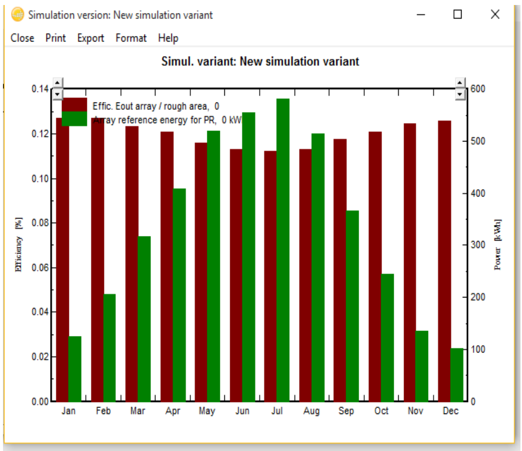

Fig. 14. Efficiency of the PV system in correlation with power production.

Additional results of the simulation are reported in *Table 1*, which represent the global radiation for each month, ambient temperature for the operating solar cells, energy produced of PV model, energy injected into grid, efficiency of PV, efficiency of system, etc.

From *Table 1* it was observed that the energy provided from PV system was 3560 kWh/year with an efficiency rate of 11.15 %, at a global horizontal radiation by 1415.6 kWh/m^2/year.

Tabel 1

Simulations report

New simulation variant

Balances and main results

Months	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	EffArrR %	EffSysR %
January	43.3	-0.98	42.5	39.5	117.6	106.9	12.71	11.57
February	69.6	1.48	70.3	66.3	194.1	183.1	12.70	11.98
March	109.9	6.69	108.2	103.2	290.7	275.9	12.35	11.72
April	142.5	11.83	139.7	134.3	366.7	349.5	12.07	11.51
May	181.7	17.93	177.6	171.2	447.8	427.5	11.60	11.07
June	195.8	21.12	189.5	183.0	466.4	445.5	11.32	10.81
July	203.9	23.72	198.6	191.9	484.2	463.1	11.20	10.72
August	178.3	23.35	175.6	169.2	431.7	413.1	11.31	10.82
September	125.0	17.13	125.4	120.3	321.0	305.4	11.77	11.20
October	85.0	11.95	83.6	79.2	219.4	206.4	12.07	11.35
November	45.9	6.36	46.1	43.3	124.7	114.4	12.45	11.42
December	34.7	0.37	35.0	32.5	95.7	85.6	12.56	11.24
Total	1415.6	11.80	1392.0	1333.9	3560.0	3376.5	11.76	11.15

4. Conclusions

The current paper presents the energy production of a PV system that was installed in a building in Bucharest, Romania. Simulations of the system have been performed with PVsyst software. It has been used to obtain information on energy production, efficiency of system and energy loss by PV system.

The simulation has clearly shown that the efficiency of photovoltaic panels decreases in summer season. This is explained by the fact that the solar cells lose energy through heat. In fact, that part of energy of solar cells is lost/consumed by cells instead of producing energy.

Matlab and PVsyst have shown that the PV module operates at the same parameters as that specified in the technical data. It is very important to know how the PV system operates, how much energy can produce and which are the losses, because in this way we'll know if the system is profitable or not.

Acknowledgment

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