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STUDY REGARDING THE ELECTRICITY PRODUCTION OF A PHOTOVOLTAIC SOLAR SYSTEM

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Abstract: *Among the available renewable resources in our country solar energy shows significant potential and can be used in the production of electricity through photovoltaic panels. The paper presents the results from the monitoring of a solar system photovoltaic connected to the grid during a year. The values obtained from measurements were then compared with the values obtained by computational simulations. Also were conducted a series of simulations to determine if the system can sustain a residential consumer. Following the analysis of the results was found that although the system's electricity production exceeds the energy requirements, only 45% of the energy demand is covered by the photovoltaic system.*

Key words: *solar energy, photovoltaic panels, electricity, energy system.*

1. Introduction

With an expansive industrialization of the last two centuries, a series of side effects with negative impact on the environment began to manifest. Among these, the most upsetting is known as the greenhouse effect. It is a process of global warming caused by reflected radiation which in the presence of certain gases will be reflected back to Earth. The first noticeable effect, is represented by the melting of glaciers, which obviously would have a devastating effect on the planet's balance.

One possible solution to this problem is to shift from energy produced from fossil fuels (oil, natural gas and coal) to the use of so-called "clean energy" such as solar energy, water, wind, wave etc.

Statistics show that around 40% of global energy consumption is due to construction (construction itself, heating, cooling, electricity consumption, etc.). In this context, designers in the field realized the importance of using alternative energy sources, of which solar energy offers great potential. In this way it aims to improve the energy balance of buildings [5]

In this paper, we focus on the use of solar energy for electricity generation. This can be done in several ways:

- the classical way of obtaining electricity having heat generation as an intermediate step;
- the possibility of direct conversion of solar radiation into electricity through photovoltaic effect, using solar cells or batteries.

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2. Generalities on PV Cells

The devices in which the conversion of light energy into electricity is achieved by photovoltaic effect are called photovoltaic generators. The most basic of these are called photovoltaic cells or photocells.

Current research in the field of solar cells are directed in several priority directions, such as reducing the costs of solar cells, improving their efficiencies, as well as finding new materials and technologies of manufacture. In this regard, if the first cells produced in the 50's had 4% efficiency, today we are at the third generation of solar cells with efficiency of 20%.

In terms of materials used in the production of photovoltaic cells, the most common are based on silicon, namely:

- with thick film: monocrystalline (c-Si) or polycrystalline (mc-Si);
- with thin film: amorphous silicon cells (a-Si) or crystalline silicon cells (μc-Si);

To obtain high power conversion systems, the connection in series and / or parallel of more solar cells is required (about 40), resulting modules of solar cells called photovoltaic panels (to be distinguished from other solar panels). Inside the panels the series connection of the cells is preferred, allowing, due to the summed voltages, the use of conductors with a smaller cross-section, compared to the parallel connection. To protect cells against the effects of junction avalanche, caused by higher potential that can arise in certain situations (eg partial shading module) must be incorporated in parallel with the solar cells protection diode.

Photovoltaic panels can be used in off-grid systems, to supply electricity to isolated consumers or in grid-tied systems. In off-grid systems a very important role is played by the storage system in order to continuous ensure the electricity demand [1,2]. In this paper is studied a grid-tied system.

3. Case Study

To understand the functioning of a photovoltaic solar system, an existing system was analyzed. The system, having an installed capacity of 138 kW, is operational since 2012 and was installed to supply electricity to a high school in Alba Iulia.

3.1. The Photovoltaic Solar System Description

The analyzed system is composed of 43 modules, each having 20 or 22 photovoltaic palels of 150W PV connected to a 4000VA inverter.

To cover the energy demand in moments of maximum consumption or when the weather conditions are unfavorable the system is connected to the national power grid.

As it can be seen in the schematic diagram of the system in Figure 1, in this case the inverters have a DC input that comes from the photovoltaic panels and an AC outlet that plugs into an electric panel through automatic fuses and then connects to the public network through a bidirectional meter.

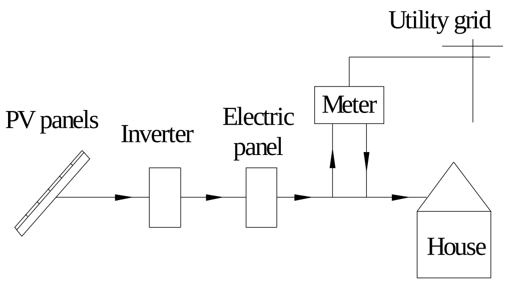

Fig. 1. *Schematic diagram of the system*

In order to determine how the photovoltaic-solar system operates information regarding the energy indicators was taken from the display of each inverter during a year of operation.

The geographical data regarding the location of the studied system are: 46˚3'53"North and 23˚36'42 "East.

The solar potential of the site can be seen in Table 1, which presents the monthly and daily average values of the solar radiation on the horizontal surface [6].

Average solar radiation values Table 1

Month	Average daily values	Average monthly values
	[kWh/m²]	[kWh/m²]
January	1,35	41.85
February	2,16	60.48
March	3,18	98.58
April	4,02	120.6
May	4,87	150.97
June	5,32	159.6
July	5,35	165.85
August	4,93	152.83
September	3,47	104.1
October	2,37	73.47
November	1,42	42.6
December	1,08	33.48

3.2. Energy Production of a 3.3 kW Module

Further are presented the results of the measurements for a 3.3 kW module, consisting of 22 photovoltaic panels of 150W each, connected to a 4000VA inverter.

Data were taken once a month over a year, from february 2014 until january 2015 and the information gathered were processed in tables and graphs. Table 2 shows the daily and monthly average values for a 3.3 kW module.

Following a year of operation the 3.3 kW module recorded an annual electricity production of 3730 kWh/year. One can notice that in december were recorded the minimum values of electricity production and the maximum value were recorded in august, namely 551kWh/month, ie an average daily production of 17.77 kWh.

Energy production Table 2

Month	Monthly values	Daily average values
	[kWh]	[kWh]
Jan.	73,42	2,37
Feb.	164,8	5,89
Mar.	298,73	9,64
Apr.	357,69	11,92
May	447,05	14,42
Jun.	532,22	17,74
Jul.	423,31	13,66
Aug.	551	17,77
Sep.	413,44	13,78
Oct.	266,6	8,60
Nov.	135	4,50
Dec.	66,96	2,16

3.3. Power Supply of a Residential Consumer

In order to determine if a 3.3 kW module can sustain the energy demand of a residential consumer a series of simulations were performed using iHoga program [3].

IHOGA (Hybrid Optimization by Genetic Algorithms) is a simulation and optimization software based on genetic algorithms used for the generation of electrical energy from renewable sources. The program can simulate or optimize stand-alone or grid-connected systems. During the simulation iHOGA calculates the power generated by PV panels as a function of irradiation and shortcut current [4]:

$$P_{PV} = \frac{I_{sc} \cdot G \cdot V_{PV} \cdot N_{PVs} \cdot N_{PVp}}{LF} \qquad (1)$$

where:

P_{PV} – power generated by PV panels;

I_{sc} – shortcut current [A];

G – solar radiation on the surface of the panels [kWh/m²];

V_{PV} – voltage generated by the photovoltaic pannel [V];
N_{PVs} – number of pannels in serial;
N_{PVp} – number of pannels in parallel;
LF – loss factor due to dirt or possible errors on the panel orientation.

Using the iHOGA software one can determine aspects related to the energy production of the system, price and CO_2 emissions.

In the performing of the simulations was considered an average daily consumption of 6.47 kWh, meaning an annual energy load of 2364 kWh. Figure 2 shows the variation of hourly energy demand for a day of december, which is considered the most disadvantaged month in terms of solar potential [3].

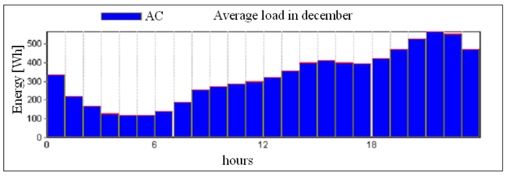

Fig. 2. *The variation of hourly energy demand for a day of december*

3.4. Simulations Regarding the Electricity Supply of a Residential Consumer

Simulations were performed during a year of the operating system considering the energy load and weather conditions the same for the remaining years of the system functioning.

Table 3 shows the results of the simulations related to the energy indicators and carbon dioxide emissions [3].

Analyzing the simulation results can be noticed that the total value of the electricity production exceeds the energy requirements by 56%. However, because solar radiation is available in a limited period over the day, the energy demand is covered only 45% from renewable energy sources, the difference of 55% is purchased from the utility grid (see Figure 3). In order to increase the percentage of renewable energy is required to install a larger number of PV panels or a battery bank [2].

By installing an energy storage system the investment cost increases with the degree of consumer energy independence as it can be seen in Figure 4.

Simulation results Table 3

Overall Load Energy [kWh/year]	2364
Unmet load [kWh/year]	1296,8
Energy delivered by PV [kWh/year]	3693
Excess Energy [kWh/year]	2532
Energy sold to AC grid [kWh/year]	2280
Energy purchased from AC grid [kWh/year]	1297
Total CO_2 emissions [kgCO_2/year]	624

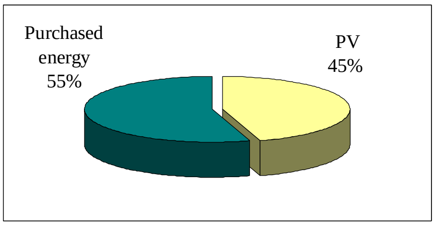

Fig. 3. *Percentage values regardind the energy demand*

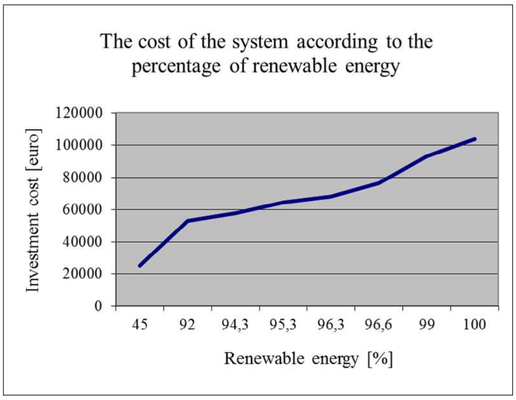

Fig. 4. *Investment cost*

In Figure 5 one can observe higher values of purchased energy in the cold season, with peaks in december, due to the short interval in which PV panels generates energy (between 9 am and 4 pm).

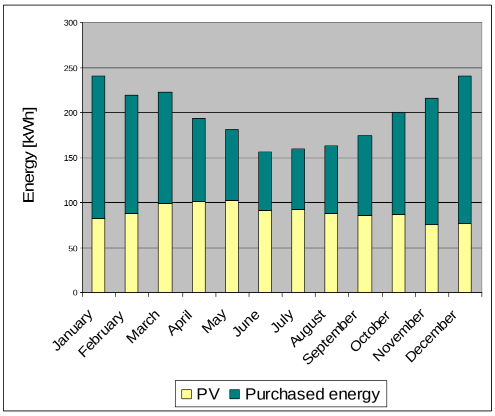

Fig. 5. *Energy demand*

In the warm season, solar radiation is available in a wider range, between 6 am and 9 pm, so that the values of purchased energy decreases to 41% of the total energy demand.

As it can be seen in Figure 6, from the total energy produced by the solar PV system only 29% is used directly by the consumer, 62% is inserted into the national grid and 9% represents losses due to conversion of energy.

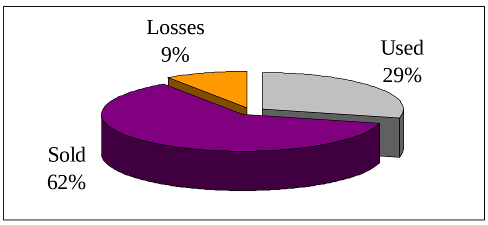

Fig. 6. *Percentage values regardind the energy generated by the system*

In Figure 7 is presented the diagram regarding the way one uses the energy generated by the PV-solar system according to the months of the year. It can be noticed the high values of energy supplied to the national grid, especially in the warm season.

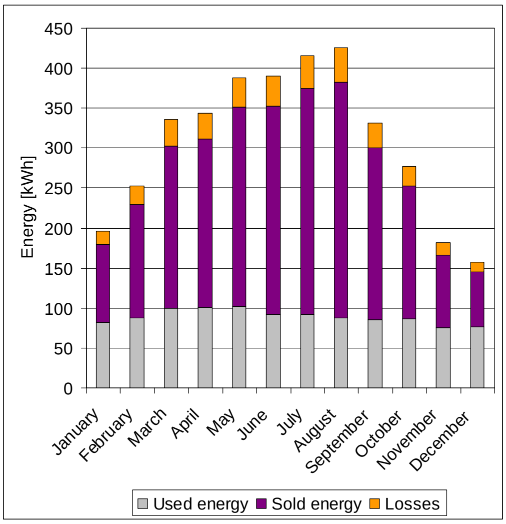

Fig. 7. *Energy generated by the system*

3.5. Comparative Analysis of the Results from Measurements and Simulations

In Table 4 was performed a comparative analysis concerning the results obtained from simulation and the measured values.

Comparative analysis Table 4

Month	Sim. [kWh]	Real [kWh]	Dif. %
January	196,5	73,42	167,64
February	252,3	164,8	53,09
March	335,4	298,73	12,28
April	343,2	357,69	4,22
May	388,1	447,05	15,19
June	390,4	532,22	36,33
July	415,4	423,31	1,90
August	425,1	551	29,62
September	331,1	413,44	24,87
October	277,1	266,6	3,94
November	181,5	135	34,44
December	157	66,96	134,47
Total	3693,1	3730,31	1,00

Even if the difference for annual energy production is very low (1%), in the chart from Figure 8 one can note the considerable differences in the case of monthly energy production, especially for the cold months. Thus, in January are the highest differences between the measured values and the simulated ones, the values obtained by simulation being almost three times (2.6) higher than the measured ones. Also in december the differences are considerable, the simulated value being 134% higher than the real one.

During the warm months, however, as can be seen in Table 4, the values obtained by simulations exceed the values obtained from measurements by up to 36%.

Since solar radiation has a variable character, the simulation results do not always reflect the experimental measurements. Performing the simulations statistical values of the average monthly solar radiation were used which are not identical every year. Therefore, for more relevant results, measurements should be repeated every year to determine an average value of the energy generated by the system.

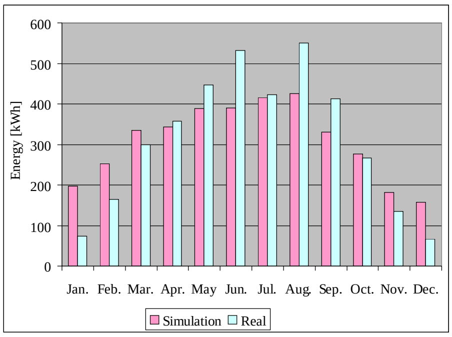

Fig. 8. *Comparative diagram*

4. Conclusions

Lately the use of renewable energies is rapidly gaining popularity due to the problems posed by the use of traditional forms of energy related both to the limited reserves and to the greenhouse gas emissions.

The gradual replacement of polluting forms of electricity generation with clean energy from renewable sources can be a solution related to a sustainable development.

Installing photovoltaic panels can lower the monthly cost of utilities and also decrease the carbon footprint on the planet. However to achieve energy independence is necessary to invest in an energy storage system, which substantially increases the cost of investment.

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