Application of solar-photovoltaic systems in rural areas

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Abstract.. *In this paper two solar energy systems using photovoltaic panels are analyzed. Since the character of solar radiation is not continuous and constant a backup system is needed to cover the energy needs in periods when the PV panels do not produce energy. If the consumer is connected to the grid the solution it is much simpler. The energy uncovered by the solar system is purchased from the national energy system and the excess energy is sold. If the connection to the utility grid is impossible or too expensive the system needs to be equipped with batteries for energy storage and generators. Thus, a series of simulations are conducted to observe the functioning of the two systems.*

Key words: energy, solar energy, photovoltaic panel, rural areas.

1. Introduction

Electricity is a major contributor of global development. It is the foundation for technological advancement and industrialization, which results in a higher standard of living. However, in Romania there are some rural areas partially connected or not connected to a centralized power grid. The extension of the main grid to low population areas is associated with high capital outlays and high transmission losses.

About 45% of Romania's population lives in rural areas, from isolated communities with few inhabitants to some relatively large communities, with a population approaching 10,000 people. In the last decade the needs of the rural population have diversified with the development of technologies, increasing the energy requirements. Thus, to ensure decent living conditions that comply to European norms the energy infrastructure must develop even in rural areas. Electricity plants must be scaled to cover the increased demand for energy or the load can be supplemented or replace with energy produced from renewable sources on site.

Renewable energy sources represents the basic components in the sustainable development of human communities whose energy demand continues to grow, the development of renewable sector being a possible answer for both consumers connected and those isolated from national electricity grid.

The solution to provide electric power to a house depends on several factors, such as:

- geographical position;

- energy demand;
- consumption chart;
- weather conditions
- distance to the nearest point of connection to the National Energy System.

In the case of isolated buildings, the optimal solution (often more advantageous) is a off grid renewable energy system [1]. In this case, is required to be equipped with an energy storage system and, optional, a generator. This solution is chosen when the connection to the national grid is difficult to achieve - because of the difficult terrain, long distances - or due to financial reasons. If the consumer is tied to the utility grid the option for a renewable energy system reduces the maintenance costs.

When we speak about off-grid system is required to have a reserve of energy to cover the demand when renewable source does not have sufficient power. This is accomplished by equipping the system with batteries and electric generator [2]. If grid connection does not raise major problems, it is recommended to replace the storage system with the National Energy System. This solution is more advantageous in several ways, namely:

- the power is provided without interruption throughout the year, regardless of weather conditions or how many consecutive days energy from renewable sources is not produced;
- excess energy is injected into the network for profit;
- the decrease of energy loss because is no longer needed to convert the energy for storage.

This paper presents two systems of electricity production using photovoltaic (PV) panels, an off-grid system and one connected to the utility grid. Using iHOGA software, a series of simulations are conducted to determine the operating mode, but also aspects related to the energy production, price and CO_2 emissions.

IHoga - Hybrid Optimization by Genetic Algorithms - is a simulation and optimization software based on genetic algorithms. It is used for the generation of electrical energy and can simulate or optimize stand-alone or grid-connected systems. During the simulation iHOGA calculates the power generated by PV panels - P_{PV}, as a function of irradiation and shortcut current [3]:

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

where,
I_{sc} – shortcut current [A];
G – solar irradiance on the surface of the panels [kWh/m^2];
V_{PV} – voltage generated by the PV pannel [V];
N_{PVs} – number of PV pannels in serial;
N_{PVp} – number of PV pannels in parallel;
LF – loss factor due to dirt or possible errors on the panel orientation.

2. The consumer characteristics

In this paper are analyzed two types of solar systems that supplies energy to a household located in a rural area of Cluj county. For this area we used the official meteorological data of solar radiation intensity presented in Table 1 [4]. The average values of the solar irradiation on the plane of the PV panells are :

- daily average irradiation 3,69 kWh/m^2 ;
- total annual irradiation 1347,06 kWh/m^2 .

Table 1

Average irradiation [3]

Month	Daily average irradiation	Monthly average irradiation	Month	Daily average irradiation	Monthly average irradiation
	[kWh/m^2]	[kWh/m^2]		[kWh/m^2]	[kWh/m^2]
January	1,35	41,85	July	5,35	165,85
February	2,16	60,48	August	4,93	152,83
March	3,18	98,58	September	3,47	104,1
April	4,02	120,6	October	2,37	73,47
May	4,87	150,97	November	1,42	42,6
June	5,32	159,6	December	1,08	33,48

Estimating the needs of a rural household, was established the energy load, considering the following consumers:

- indoor lighting;
- outdoor lighting;
- electronic appliances: fridge, TV , computer, washing machine, iron.

Based on the energy consumers, and taking into account the normal regime of life in rural areas, was considered an average energy consumption of 3.62 kWh/day and the following loads:

- maximum AC load : 339 W;
- hourly AC load : 151 W.

In Fig. 2 is presented the consumption chart for a day during the cold season.

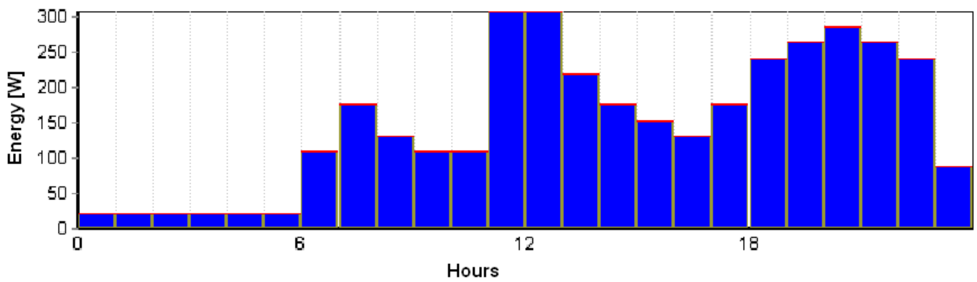

Fig. 1. Graph of consumption for a day

Simulations were performed during a year of the operating system, and the weather conditions and load are considered constant for the remaining years of the system functioning (25 years).

3. Off-grid solar energy system

Performing the simulations for the off grid solar energy system [2], the algorithms have determined the optimal configuration of the system according to the energy load required, havind the following components – Fig. 2:

- 12 PV panels of 175Wp each, with a total power of 3 kWp ;
- 8 batteries, having a capacity of 200Ah each;
- AC generator diesel of 1,9 kVA;
- inverter, 900VA ;
- PV battery charge controller of 149A ;
- Battery charger of 1900W.

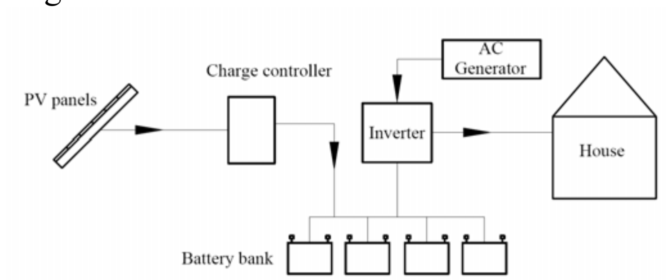

Fig. 2. Components of a solar-photovoltaic energy system

Following the simulation, it can be seen in Fig 3 the chart with the monthly and annual average values of electricity production using photovoltaic panels. In Tables 2 are presented the results of the simulations on the total energy production, excess energy, unmet energy and CO_2 emissions. It may be noted that energy demand is covered entirely by the PV panels and batteries, the generator being for backup.

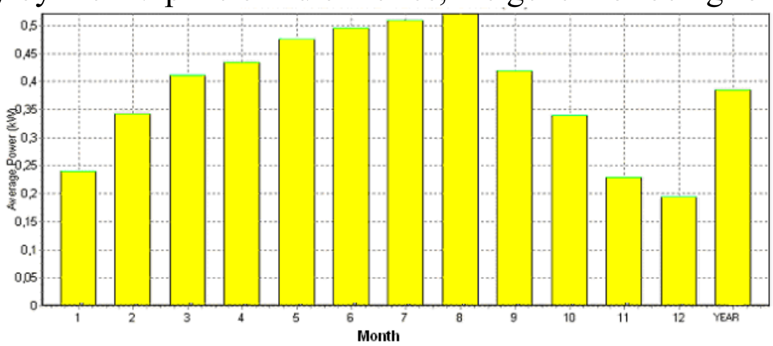

Fig. 3. Monthly and annual average PV panels power

Table 2

Simulation results

Overall Load Energy [kWh/year]	1327
Unmet load [kWh/year]	0
Energy delivered by PV [kWh/year]	3367
Energy delivered by generator [kWh/year]	0
Excess Energy [kWh/year]	1728
Energy charged by Batteries [kWh/year]	737
Energy discharged by Batteries [kWh/year]	739
Total CO_2 emissions [kg CO_2/year]	181

Fig. 4 describes how the system works over a period of 24 hours during the warm season (August). It can be seen that up to 7am the batteries are discharging, providing electricity to the consumer. During the day, the energy demand is covered by the PV panels. From the surplus energy the batteries are charged (from 7 am until 12 am) but the excess energy produced after 12 am is lost.

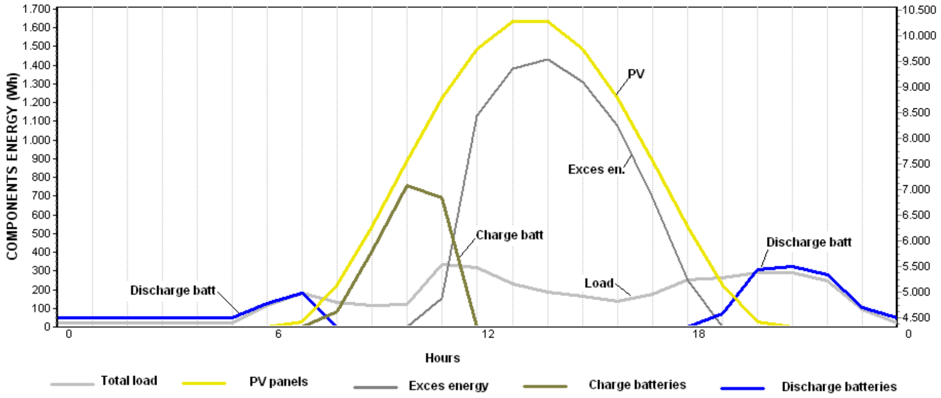

Fig. 4. Simulation of the solar system functioning in august

In Fig. 5 is presented the simulation of the solar system functioning during a day in the cold season (December). Since solar radiation is not so strong, it can be seen that this time we do not have a large amount of excess energy. The PV panels are covering the energy load in a shorter period - between 9 and 16. Also the period in which the batteries can charge is limited and the time in which they must provide the necessary energy is longer.

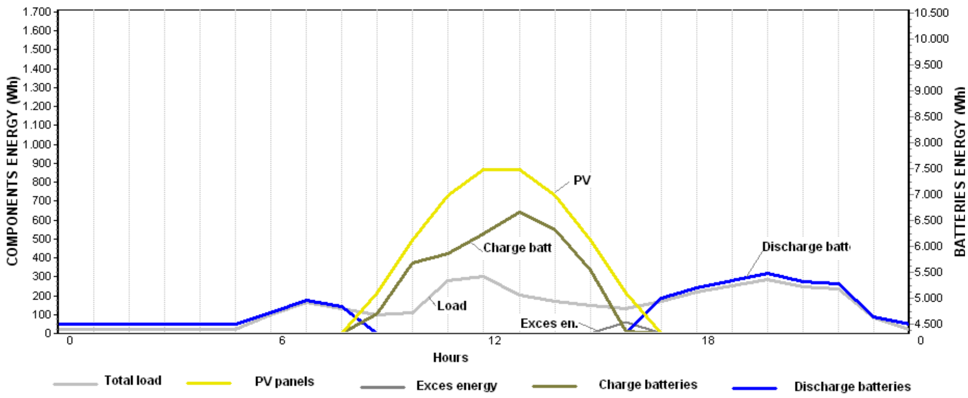

Fig. 5. Simulation of the solar system functioning in a day of december

In Fig. 6 the percentage costs of the analyzed system are shown. It can be seen that the batteries hold the highest share of the total cost -38.15%, as these have a lower lifespan than the other components of the system and must be replaced after a certain number of charge/ discharge cycles. The cost of the PV panels represents only 19.5% of the total investment, a large percentage being held by the auxiliary equipment - 30.7%.

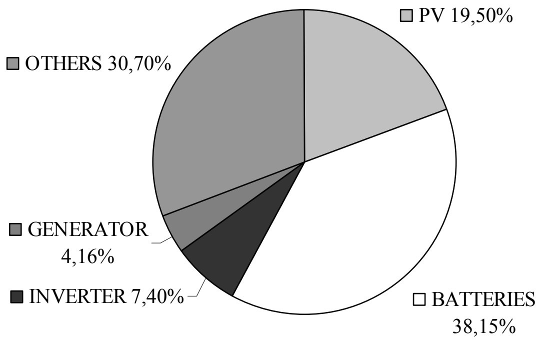

Fig. 6. Percentage cost of the equipments

4. Grid-connected solar energy system

For the grid-connected solar energy system, simulations were performed, havind the following components – Figure 3:

- 12 PV panels of 175Wp each, with a total power of 3 kWp ;
- inverter, 900VA ;

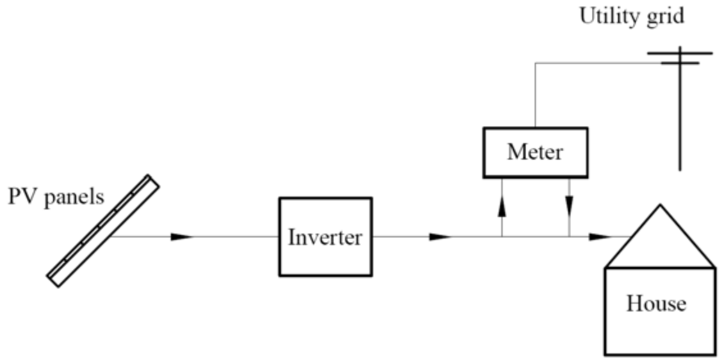

Fig. 7.Components of a solar-photovoltaic energy system

Performing the simulations for the solar-PV system are obtained the results shown in Table 3. It can be noticed that from the total energy consumed only 57.3% is produced from renewable sources and 42.7% is provided by the national electricity grid. Of the total energy produced by photovoltaic panels only 22.5% is used for consumption, the rest being sold to the utility grid.

Table 3

Simulation results

Overall Load Energy [kWh/year]	1327
Unmet load [kWh/year]	566
Energy delivered by PV [kWh/year]	3367
Excess Energy [kWh/year]	2528
Energy sold to AC grid [kWh/year]	1800
Energy purchased from AC grid: [kWh/year]	566,4
Total CO_2 emissions [kg CO_2/year]	322

In Figures 8 and 9 is shown the functioning of the grid-connected system for a period of 24 hours during the cold and warm season.

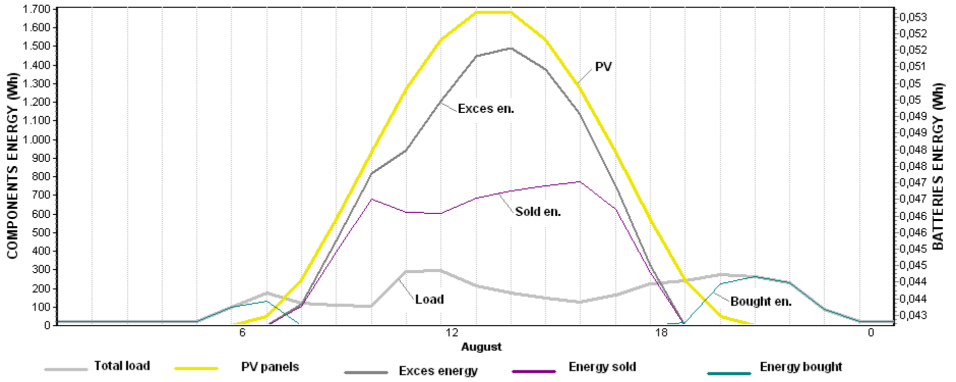

Fig. 8. Simulation of the grid-connected solar system functioning in august

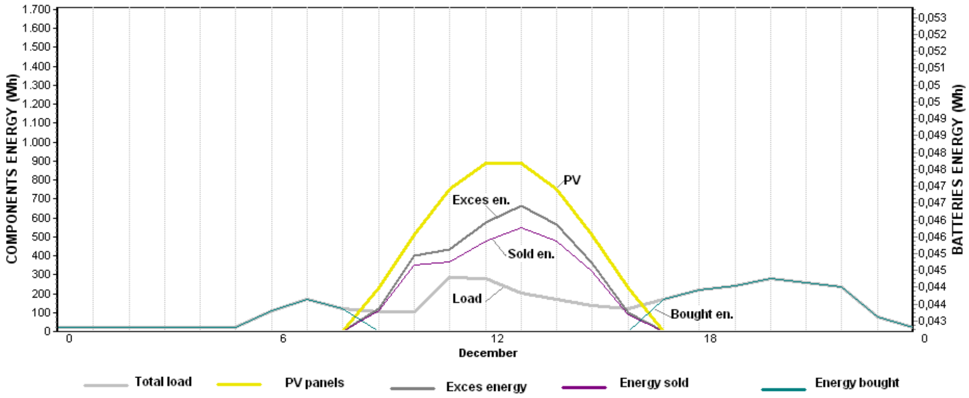

Fig. 9. Simulation of the grid-connected solar system functioning in december

In Fig. 10. a comparison was made between the total cost of investment for both systems. It can be seen that the cost of the off-grid system is approximately 5 times higher than the grid-connected system. In Fig. 10.b. the levelized cost of energy is compared for the two systems.

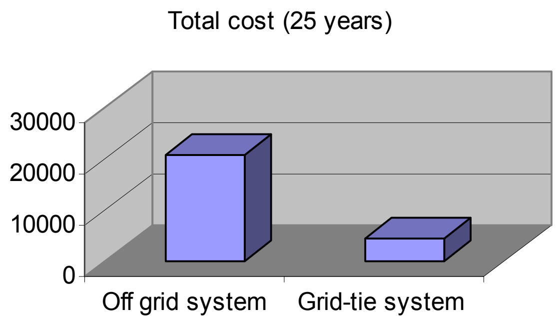

Fig. 10. Economical comparison between the two solar systems

6. Conclusions

Installing an electricity production system using photovoltaic panels can be considered both for isolated consumers, as well as when consumers are connected to the national grid. In the case of isolated consumers an autonomous system is chosen equipped with battery bank - which stores the exces energy. In the case of grid-connected systems, the national grid acts as a battery, having the advantage that no energy is lost through conversion.

Grid-connected systems have a number of advantages, such as:

- reduced cost of the investment;
- lower number of equipments;
- eliminate the risk of remaining without electricity in case there are several days without sun;
- excess energy does not require storage;
- depreciation of the investment by selling the excess energy.

The off grid systems have the advantage that can be easily install to supply electricity where the connection to the utility grid is not possible or requires expensive investment. Unlike grid-connected systems, these are much more complex, so the price is also higher. In this case, to supply continuous energy to the consumers it requires a back-up system such as battery bank or AC generator. The disadvantage of using batteries, besides the higher price - because they have lower lifetime than the rest of the components and must be replaced - is that through conversion a significant amount of energy is lost. The ideal case is to use energy when and where is produced, but this solution is difficult because of the unstable character of solar energy.

In the context of sustainable development, renewable energy resources are the optimal alternative to solve energy issues and protection against environmental degradation [5].

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