ANALYSING THE PERFORMANCE OF PHOTOVOLTAIC SYSTEMS IN THE MARAMURES REGION

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Abstract: *This paper presents the performance of several types of inverters and the data they collected in the MARAMURES region of Romania. They were run in various different environments, angles of inclination and geographical positions. Each type of inverter is equipped with an application which helps the operator keep a record of daily production, track instant production and even check the monthly and annual power output. The last part compares the real energy production with a forecast generated by the PVGIS platform. This shows the differences in efficiency between two photovoltaic installations of the same type and size, due to different angles of elevation and azimuth.*

1. INTRODUCTION

Green energy is one of the key requirements for a sustainable future. The global push to promote the transition to green energy has increased rapidly in recent years. This has led to a sharp fall in prices, making renewable energy much more accessible. Iceland, for example, has extensive geothermal resources, while places such as the Scottish Highlands are suitable for wind energy. While the United States has invested in hydropower, in other areas, solar power is best. Each type of renewable energy comes with advantages and disadvantages, often related to supply. Therefore, the best solution often uses a combination of different energy sources.

The development of solar energy is not new. It started more than a hundred years ago, in the midst of the industrial revolution, when Henry Becquerel discovered the photovoltaic effect. This allows for the production of electricity directly from the sun's rays. For many consecutive years, photovoltaics remained just a curiosity, as the transformation of solar radiation into electricity was too inefficient. Due to the advent of the transistor and the continuing advancements in semiconductor technology, the efficiency of photovoltaic panels has increased significantly. Over the years, efforts have been made to increase the efficiency of photovoltaic energy, making it more and more practical [1].

One of the most promising types of unconventional energy sources in the world is photovoltaic energy. Compared to traditional fossil fuels, such as coal, oil, and gas, or even nuclear energy, the advantages are quite clear. Solar energy does not emit greenhouse gases, does not require the use of radioactive elements, and requires low levels of maintenance. Furthermore, photovoltaic systems require comparatively few components, and the contained photovoltaic cells have a lifespan of several decades.

Thanks to modern power generators, which can easily be installed in every house, individual users can generate their own energy, quietly and without any fear. In contrast, wind and hydropower often require complex turbines to drive generators and produce electricity. These turbines and generators are noisy and contain moving parts which wear and break down over time, thereby necessitating more frequent maintenance [2-7].

EU legislation on the promotion of renewable sources has evolved significantly over the last 15 years. In 2009, EU leaders set a target for 20% of EU energy consumption to come from renewable energy sources by 2020. In 2018, the target was adjusted to 32% of EU energy consumption to come from renewables by 2030.

In July 2021, in view of the EU's new climate ambitions, the co-legislators received a proposal to revise the target to 40% by 2030. Debates are currently taking place on the future policy framework for the period after 2030 [8].

In this study, we try to determine the level of investment required for solar power plants and estimate the required time period for the return on our investment. All the calculations are based on statistical data gathered over the years from various web platforms.

2. PHOTOVOLTAIC SYSTEMS

The basic component of a photovoltaic system is the photovoltaic cell which is made of semiconducting materials, their properties being used to capture solar radiation. Through the inverter in the photovoltaic system, solar radiation is transformed into a direct current, which in turn is transformed into alternating current [9-10].

In more than half of Romania, the annual solar irradiance ranges from 1000 to 1300 kWh/m^2/year. The most important regions of Romania with high solar potential are the Black Sea coast, Dobrogea, and a great portion of the Romanian plain, with an average irradiance of 1600 kWh/m^2/year [11]. This climate allows for the efficient operation of solar panels from March until October.

Romania's experience in solar energy represents a competitive advantage for the future development of this area, as the country is a pioneer in the field. Between 1970 and 1980 around 800,000 m^2 (0.8 km^2) of solar collectors were installed, placing the country third worldwide in the total surface of photovoltaic cells. These research efforts generated an important human and infrastructure potential. Between 1984 and 1985 the peak of solar installations was achieved but after 1990 unfavourable macroeconomic developments led to the abandonment of production and investments in the solar energy field. Today about 10% of the former installed collector area is still in operation [12].

3. INVERTERS

An inverter is a device that converts direct current (DC 12V) into alternating current (AC 240V). Most household appliances are powered by an alternating current of 240V. When the energy is taken from a direct current source, a generator, or a battery, the inverter has the important role of transforming this energy into alternating current. In conclusion, the inverter can be thought of as a *bridge*, connecting the direct current power source and the alternating current device.

Over the years, the technology used in common inverters has advanced enormously, and modern appliances are equipped with numerous refined functions. This allows the inverter to operate at a heightened level of performance (depending on the number of volts required to power the device), thus facilitating electricity savings and easing installation and transport.

The quality of an electrical signal transmitted by a pure sine wave inverter is essential to power most electrical devices, as they are highly sensitive to the nature of the electrical signals they receive.

3.1. Single-phase inverters

Single-phase inverters are predominantly used by residential consumers and are mainly found in apartments. Therefore, the power of such a connection cannot exceed 9.9 kW. The advantage of these devices is the reduced cost when compared to a three-phase inverter, and the compatibility with single-phase electrical networks.

The Fronius Primo without a transformer (*Fig. 1*), is an ideal compact single-phase inverter for homes and small businesses, applications with power categories from 3.8 to 8.2 kW, in accordance with the ESA rules for residential applications.

Fig. 1. Fronius Primo Inverter

There are many inverters on the market (*Fig. 2*.) (Fronius, Huawei, Goodwe, Solis, etc.). All of them have an online platform for monitoring and some can even be controlled remotely.

Fig. 2. Different inverters types (Huawei and Solis)

A conventional single-phase inverter is based on four insulated-gate bipolar transistors (IGBTs) each containing an anti-parallel diode to provide bidirectional current. This is controlled through Pulse-width modulation (PWM) which helps to achieve the desired voltage. Finding the desired voltage is usually done through an external adjustment loop at the upper level, which then enables PWM generation.

Among other things, the external control loop must be able to supply the required sinusoidal frequency and the correct amplitude in relation to the bus voltage.

3.2. Three-phase inverters

Three-phase systems are usually used for industrial applications or for buildings containing large consumers. They convert direct current to three-phase mains current. This allows for a greater distribution of electricity, as it allows a DC voltage to be converted into a balanced three-phase sinusoidal voltage. Compared with single-phase inverters, three-phase inverters can support more switches to increase the accuracy of the proposed voltage while also reducing harmonics.

The Fronius Primo can operate efficiently at a maximum input voltage of 600 V. For increased efficiency and extra cost savings in commercial applications, the Fronius Primo can operate at a maximum input voltage of 1000 V. The industry's top features now come as a standard with the Fronius Primo, including dual maximum power point tracking, spring failure protection, and integrated wireless monitoring. The integrated SunSpec Modbus interface enables uninterrupted data monitoring and recording via the Fronius online and mobile platform, Fronius Solar-Web, which displays current data and a wide range of settings.

Inverters connect regularly to their own smart meters (*Fig. 3*), through which they can control the power supplied to the grid. This is especially useful to maintain a value of 0 Wh if no energy is to be supplied to the electrical grid and production is only intended for in-house consumption. The smart meters are placed in the main electrical panel monitoring the entire electrical network. They display the amount of energy produced by the solar panels, as well as the power consumed within the system, with the help of inverter communication.

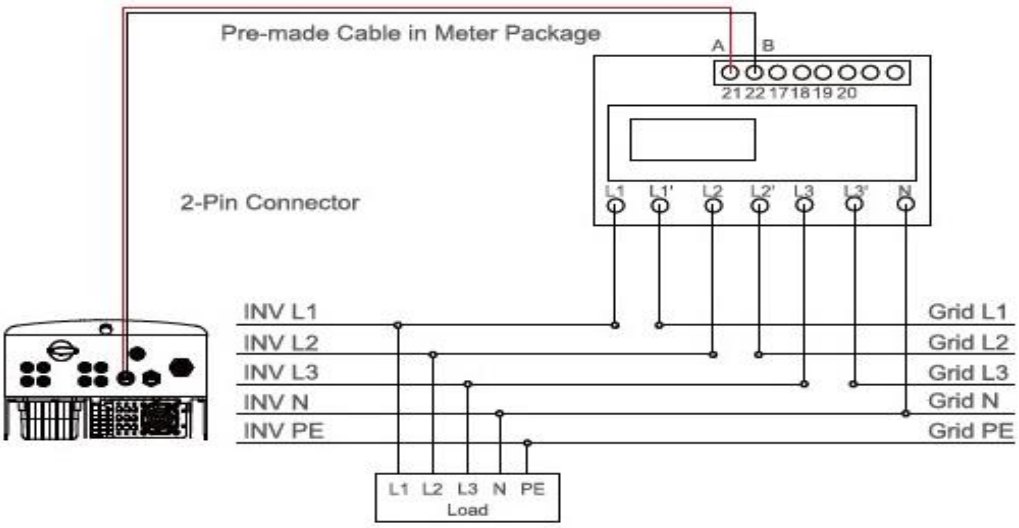

Fig. 3. Connection diagram of a three-Phase with a smart meter

4. ANALYSIS OF THE PERFORMANCE

This application of inverters comes for helping the installers with the role of configuring the appropriate settings depending on the installation locations of the photovoltaic systems. The application for the operators of the photovoltaic system allows them to visualize the data production in real-time and a history of the energy production for months and years.

With this, the operators can approximate the energy production and optimise energy consumption by operating the most power-hungry appliances when the photovoltaic system has the maximum output.

This paper analyses different characteristics of photovoltaic systems (type, angle position, azimuth, etc.) in comparison with the predicted quantity of energy provided by the statistical data on the PVGIS (Photovoltaic Geographic Information System) platform. All these characteristics influence the daily energy generated by solar power plants, which is crucial information needed to calculate the investment efficiency of solar systems.

We analyse systems placed in the same region, to ensure constant weather conditions. However, the structural orientation varies. The first solar system is mounted on a tin roof with an elevation of 25° and azimuth of -16.60°. The second system is also mounted on a roof with an elevation of 35° and azimuth of -85° (*Fig. 4*).

Fig. 4. Comparing positions of both solar systems

These two particular solar systems were chosen for comparison as they are located in the same region in Lapus County, have the same installed power of 3kW, and have the same type of Fronius Primo inverter for better accuracy of the measured results.

All inverter platforms are password protected and can only be accessed by the installation company or the owner of the system. The platforms provide information related to the daily, weekly, monthly and annual energy production, the internal energy consumed, the amount of money earned from generation, the prevented carbon dioxide emissions and much more. All these functions allow for better monitoring of the solar system and its efficiency.

Analysing the daily production between the two systems, there is a clear difference of a few hundred watthours per day on the 22 of June 2022 (*Fig. 5*).

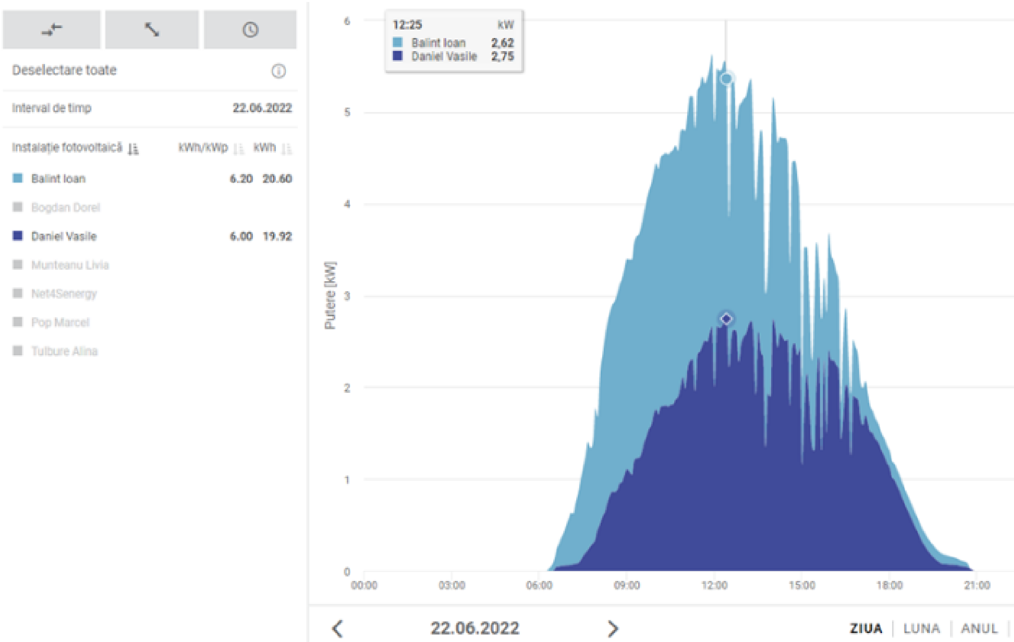

Fig. 5. The energy produced by the two systems on the 22nd of June 2022

For the whole month of June, the difference amounts to approximately 15 kWh, which equates to 3% more energy against a monthly reference output of 500 kWh (*Fig. 6*).

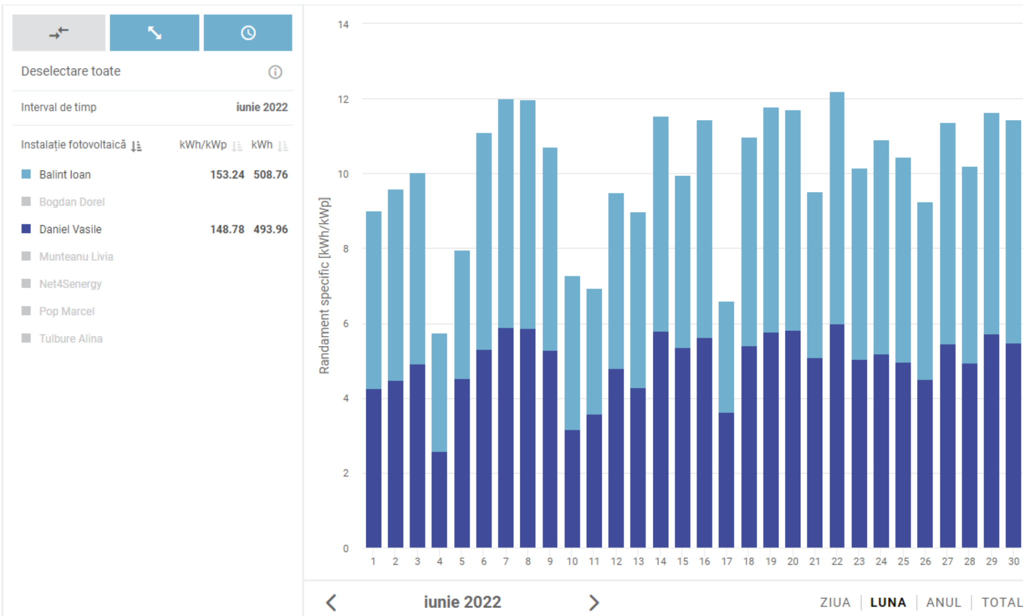

Fig. 6. The energy produced in June 2022 by the two systems

Based on this information the amount of energy produced at these locations can be forecasted. The values from the forecast (*Fig. 7*) can then be compared to the real output achieved after the system was installed (*Fig. 8*). In October 2021, the real value of 311 kWh was substantially higher than the 280 kWh forecasted by the PVGIS platform. Of course, the PVGIS platform provides an approximative value based on statistical data collected over the years and it is obvious that the weather can be different from year to year.

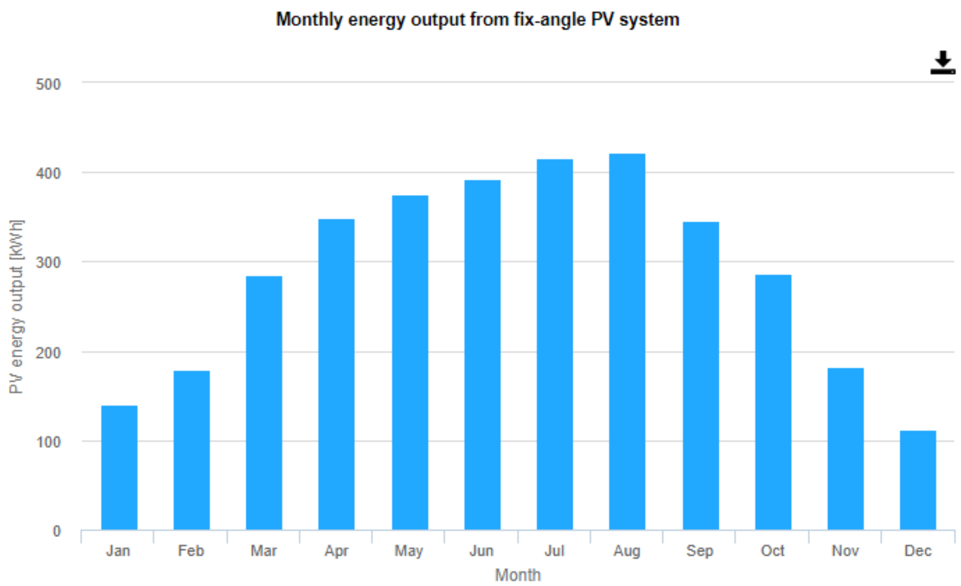

Fig. 7. Monthly forecasted energy in Lapus Country

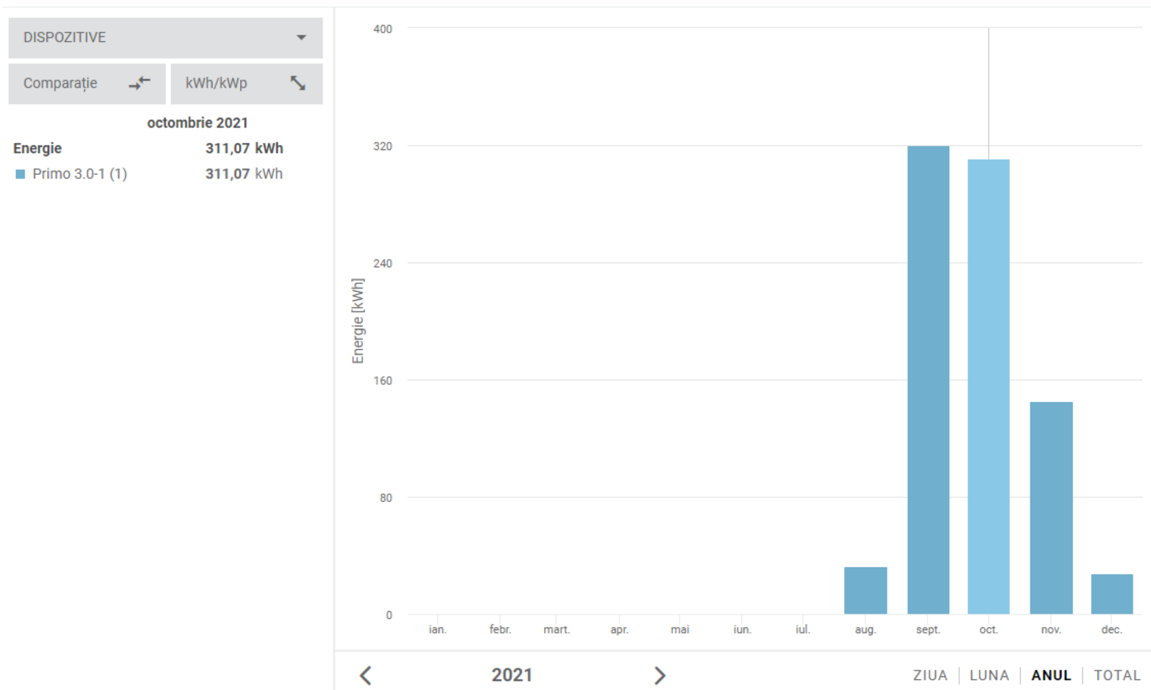

Fig. 8. Energy produced monthly in 2021 by the first system

We compare another month with PVGIS platform (*Fig. 9*), now from June 22 when we have generated energy by 494 kWh in comparison with 285 kWh from statistical, comparison is important because with statistical data we have a value of start for calculating the period of recover our investment in the solar system.

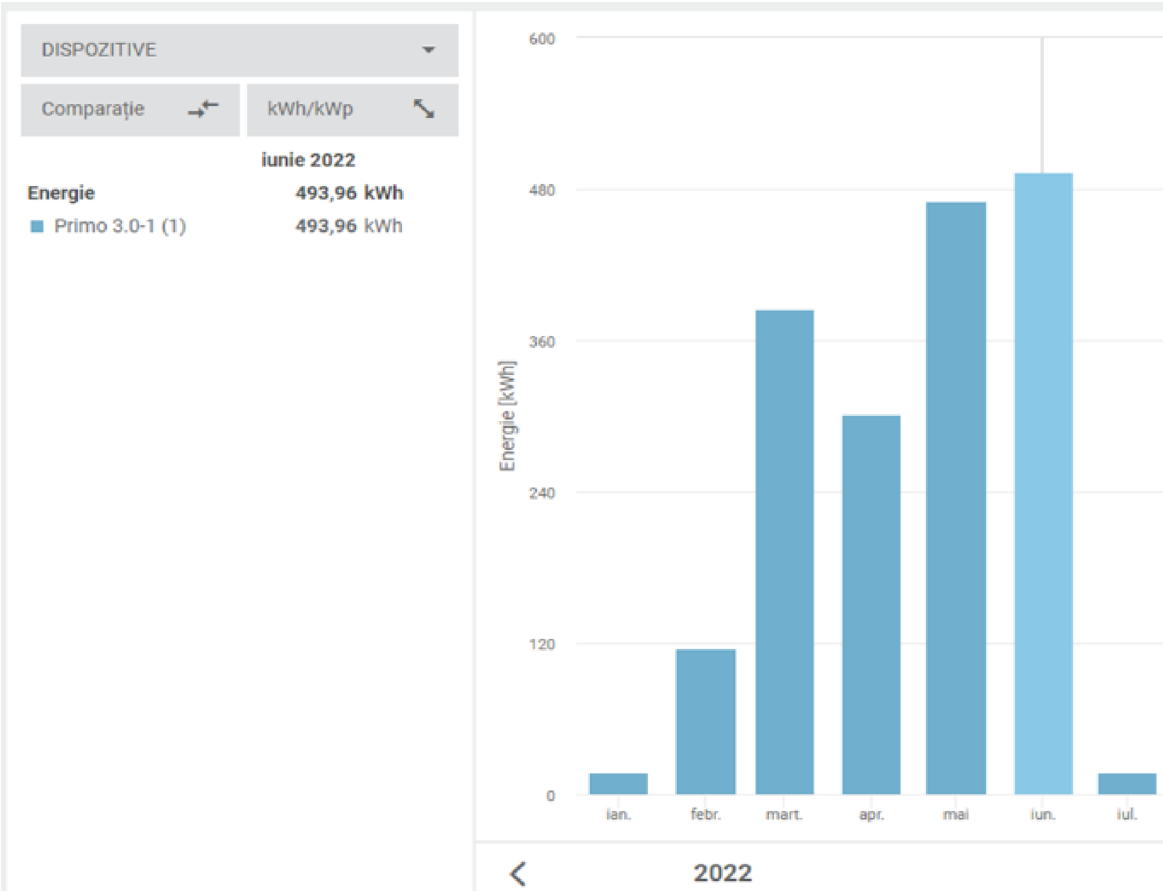

Fig. 9. Energy produced in June 2022 by the first system

5. CONCLUSIONS

Considering that both systems operated in the same weather conditions, the additional energy generated by the second system may be the result of the different angles of elevation, azimuth and inclination of the solar panels.

It has been shown that the monthly energy produced by the system was higher than the forecast for all months of the year, which indicates that the investment in the solar system will be recovered more quickly than anticipated (around one year less).

Nowadays, it is important that all the aspects of renewable energy are considered. Solar panels are easily available for everyone, but these systems are not cheap. Investments can often be recovered within 10 years and with new legislature and subsidies in Romania, investments can be recovered in as little as 6 years for on-grid systems.

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