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METHODOLOGY FOR ASSEMBLING PV SYSTEMS FOR THE NEEDS OF LOW-POWER CONSUMERS

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Abstract

This article presents a methodology for designing a photovoltaic power plant for supplying low-power loads. The main steps in the design and selection of the individual components that make up the plant are presented, such as the type of photovoltaic modules, the selection of inverters, etc. Software was used for designing and sizing the plant, with the help of which an assessment of the return on investment was also made. The presented article is useful for students, doctoral students and young specialists in the design of different types of photovoltaic power plants with different applications.

Keywords: Energy efficiency, optimal energy flows, PV plant.

INTRODUCTION

With the development of modern technologies and the increased penetration of various decentralized sources of electricity production, as well as energy storage elements, numerous methodologies for their design and construction are presented. In photovoltaic power plants, there are several main factors that must be taken into account, such as location, solar radiation, load schedules and economic requirements.

When selecting and determining a suitable site for the construction of a photovoltaic power plant, it is necessary to determine specific locations, in which factors such as land availability, possibility of connection to the distribution network, as well as distance to it must be taken into account. It is also necessary to conduct technical studies and an assessment of soil bearing capacity to determine the need for land grading, clearing, and stability. Data on solar radiation in a specific region can be taken from meteorological sources such as NASA, Meteonorm, or local databases[1-3]. There are different ways to build a photovoltaic power plant depending on its application. It is necessary to assess the load capacities and possibilities for connection to the distribution and transmission grid. According to the size of the plant, they can be divided into utility-scale, commercial or residential. When determining the load profiles, it is necessary to study databases for daily, monthly and annual electricity consumption for optimal determination of capacities. When connecting to the distribution grid in a specific region, local grid capacity, voltage levels, interconnection standards, and regulations must also be taken into account.

This article presents a study of a photovoltaic power plant in a villa area near the city of Pleven. Real data on location, solar radiation and ambient temperature were used. The implemented photovoltaic power plant project is effective because in the specific region the use of the house is seasonal. Another reason is the uneven load of the local network due to the specific location. The main advantage of the construction is the provision of continuous power supply during the daylight hours and

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regulation of the local network capacity[4-6].

EXPOSITION

Fig. 1 presents a photograph of the specific house and the chosen location of the photovoltaic power plant.

Fig. 1. *Location of the PV plant*

Figure 2 illustrates the energy balance of the photovoltaic system throughout different months of the year. The graph includes the following components:

- Generated Energy: The amount of energy produced by the system varies according to sunlight hours and solar intensity. The highest values are observed during the summer months (June, July, August) when daylight hours are longer and solar intensity is stronger.
- Energy Fed into the Grid: During months with higher production, the excess energy is fed into the grid, indicating that self-consumption does not use all the energy produced.
- Self-Consumption: Part of the generated energy is directly used to meet the object's energy needs. During months with fewer sunlight hours (for example, winter months), self-consumption covers a significant portion of the generated energy, and the amount fed into the grid is minimal.
- Electrical Loads: This shows the total electricity consumption of the object for the respective month. During the summer period, the energy from the PV plant covers a larger portion of the load, while in winter, additional energy sources are needed to cover consumption[7-10].

This energy balance shows that the system generates more energy during the summer months, while in winter, additional power is required to meet demand.

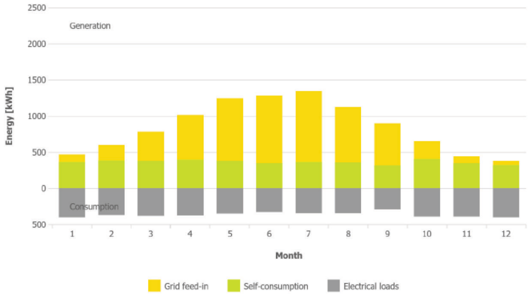

Fig. 2. *Energy flows of the PV plant*

Figure 3 presents the distribution of the PV plant's energy yield throughout the year, showing the total amount of energy produced each month. Key observations include:

- Peak Production: From May to August, production reaches and exceeds 2000 kWh, with June and July being the most productive months, yielding around 2500 kWh.
- Minimum Production: During winter months (November to February), energy production is significantly lower, reaching around 500 kWh. This reflects the seasonality and reduced solar radiation during this period.

This seasonal variation highlights the need for an additional energy source in winter and shows that the installation is more efficient for objects with high summer needs.

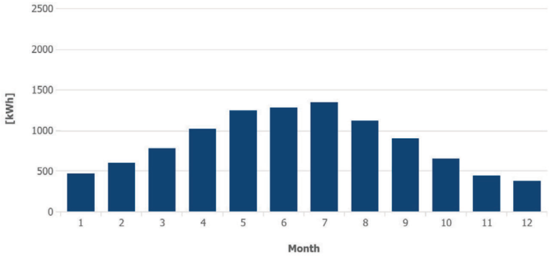

Fig. 3. *Energy yield of the PV plant*

Table 1 provides detailed technical specifications of the installation, divided into the south and north sides. Key parameters include:

- Number and Power of PV Modules: Both sides (south and north) have 12 PV modules each, with a total peak power of 5.16 kWp for each side.
- Typical and Maximum Voltage of PV Modules: The typical voltage of the PV modules is 357V, allowing for stable system operation. The maximum voltage is set at 1000V for safety.
- Maximum Operating Current and Short-Circuit Current: The inverter is designed to operate with a maximum input current of 24 A for each MPPT (Maximum Power Point Tracking) point, with the short-circuit current limited to 37.5 A. These parameters are essential to prevent overload and ensure system safety.

This information provides clarity on the system's capacity and potential for connection with other devices, such as inverters and controllers.

Table 1 - results of the design of the specific photovoltaic power plant.

	South side	North side
Number of strings:	1	1
PV modules:	12	12
Peak power (input):	5.16 kWp	5.16 kWp
Inverter min. DC voltage (Grid voltage 230 V):	150V	150V
PV typical voltage:	357V	357V
Max. DC voltage (PV module):	1000V	1000V
Max. PV voltage	512 V	512 V
Inverter max. operating input current per MPPT:	24 A	24 A
Max. MPP current of PV array:	13.5 A	8.6 A
Inverter max. input short-circuit current per MPPT:	37.5 A	37.5 A
PV max. circuit current	14.2 A	9.1 A

Two cases of use of produced electricity were also considered. In case 1, without increased self-consumption was considered and the results are presented in Fig. 4.

In this scenario, presented in Figure 4, the photovoltaic system operates without optimization for increased self-consumption:

- Production and Grid Feed-in: The total annual energy yield is 10,198 kWh, of which 7,783 kWh is fed into the grid. This shows that most of the produced energy is not used on-site but is sold back to the grid.
- Self-Consumption: Only 2,415 kWh of the generated energy is used on-site. This represents a relatively low level of self-utilization, increasing dependence on external electricity sources.
- Purchased Additional Energy: Due to the low level of self-consumption, 1,985 kWh of electricity needs to be purchased, resulting in additional costs.

This scenario demonstrates that, without measures to increase self-consumption, a significant portion of the energy is lost by feeding it into the grid instead of covering the object's needs.

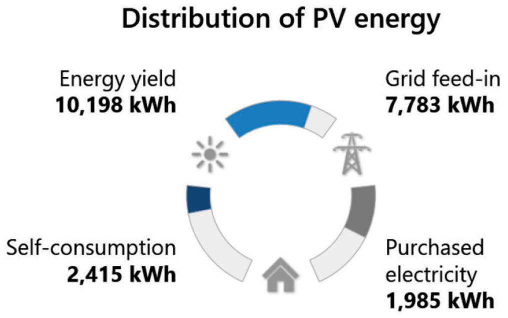

Fig. 4. *Without increased self-consumption*

In the second scenario, shown in Figure 5, the PV plant's energy is optimized for increased self-consumption:

- Production and Grid Feed-in: The total energy produced remains the same (10,198 kWh), but the amount fed into the grid is reduced to 5,868 kWh. This is achieved by increasing the self-consumption of energy, reducing dependence on the grid.

- Self-Consumption: Self-consumption has significantly increased to 4,330 kWh, nearly doubling compared to the previous scenario. This leads to more efficient use of the generated energy and minimizes the need for additional electricity.
- Purchased Additional Energy: In this scenario, the purchased energy is reduced to only 317 kWh, which is significantly lower and contributes to cost savings.

This optimization for self-consumption highlights the system's efficiency when energy storage measures or load management automation are used. This results in significant savings and more sustainable system operation.

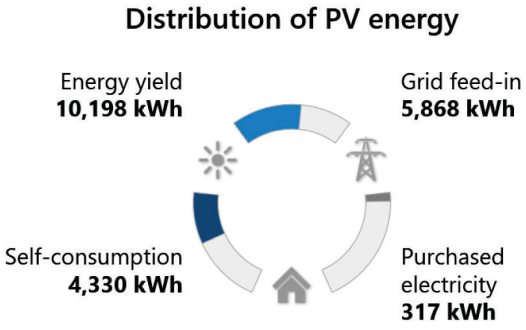

Fig. 5. *With increased self-consumption*

Based on the data in the figures and table, the following conclusions can be drawn:

- The PV plant is especially efficient during summer months, generating large amounts of energy.
- Optimization for increased self-consumption significantly reduces grid dependence and costs for purchasing external energy.
- Without such optimizations, a substantial amount of generated energy is fed back into the grid rather than being used locally.

This analysis emphasizes the importance of optimization measures, such as energy storage and intelligent load management, to achieve maximum efficiency and economic benefit from the photovoltaic system.

CONCLUSION

In conclusion, the presented methodology for assembling photovoltaic (PV) systems for low-power consumers demonstrates the viability and effectiveness of PV technology for seasonal and unevenly loaded areas. By carefully considering factors such as geographical location, solar radiation, and grid connection requirements, the system design maximizes energy production while addressing site-specific constraints. The case study highlights the potential of PV systems to provide reliable, renewable energy that reduces dependency on traditional power sources, especially in regions where energy demands fluctuate. Furthermore, the study underscores the importance of aligning the system’s technical specifications with the intended usage patterns, as optimizing self-consumption directly influences economic and environmental benefits. This methodology offers a valuable framework for designing PV systems tailored to specific consumption profiles, contributing to more sustainable and resilient energy solutions.

This study demonstrates that proper design and optimization of photovoltaic (PV) systems for low-power consumers can significantly enhance efficiency and return on investment. The presented methodology is based on an analysis of specific conditions, making it applicable to the design of PV systems across various climates and consumption profiles. The study results underscore the importance of adapting the system to the consumption characteristics, showing that PV systems can effectively stabilize local grid loads, especially in areas with uneven or seasonal consumption.

The proposed methodology is valuable not only for PV system specialists but also for students and young engineers seeking to deepen their knowledge in the design and optimization of renewable energy sources. By combining technical analysis with economic assessment, this research contributes to establishing photovoltaic technology as an efficient and sustainable solution for the energy needs of small consumers.

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