Energy and economic analysis of the use of photovoltaic in energy systems

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Energy policy of Poland in a balanced way has to provide security of energy supply, increase the use of its own resources and promote the sustainable development of different electricity generation technologies. The established aims of climate and energy policy will be difficult to achieve without efficient technologies based on distributed generation. In this context, the importance of the development and use of photovoltaic systems is growing. Photovoltaics is one of the most promising technologies and the possibilities of its use in various scale energy systems make it an effective and safe source of energy and an important part of a stable and independent energy mix in the future.

KEYWORDS: photovoltaic, renevable energy sources, energy analysis, economic analysis, simulation modelling

1. Introduction

Poland is obliged to increase by 2020 the share of energy from renewable sources in the energy balance to 15%. The achievement of this goal requires an increase in the number of projects in the energy sector. In this context, the development of investment in the field of photovoltaics seems to be expedient. To make this goal achievable, conducive legal solutions are necessary. The law on renewable energy sources, which assumptions were first presented by the Ministry of Economy in 2011, has raised great hopes among the producers of energy from renewable sources. In one of the versions of the law, for the first time in Poland, the introduction of a tariff Feed-In Tariff (FiT) for electricity was proposed. This system of support was sent to the investors in micro and small renewable energy systems. The introduction of such a support system is to determine for a set time an official price for electricity receivable from the producer of renewable energy. The type of FiT support is widespread in the world, used by over 50 countries and is the prevailing system of support in the European Union. So far, the existing system of certificates of origin did not influence significantly the development of the micro-installations RES [2, 5].

2. Basic parameters of cells

Conversion of solar energy into electrical energy, in a direct way is via a photovoltaic cell. It is a semiconductor device containing in its structure p-n junction. At present there are a few more generations of photovoltaic cells in the market. Photovoltaic Generation I cells based on silicon p-n junction type have efficiencies of the order of 17-22%, but the relatively high cost of production. These are the most common types of cells, including monocrystalline cells (efficiency of about 18-22%), polycrystalline cells (14-18% efficiency), and amorphous cells (6-10% efficiency). Photovoltaic Generation II connector type p-n, built with the use of materials such as gallium, cadmium telluride (CdTe), a mixture of copper, indium, selenium (CIGS), and amorphous silicon. They are much cheaper to produce, but have a lower efficiency compared to the first generation of cells. The most common cells of the second generation are CdTe cells made from cadmium telluride (efficiency 10-12%) CIGS cells made from a mixture of semi-conductors such as copper, indium, gallium, selenium (efficiency 12-14%). Third Photovoltaic Generation cells are deprived of the p-n junction. This group includes various advanced technologies such as cell using organic polymers. Regardless of the type and production technology, each photovoltaic module can be characterized by several parameters, which provide information about their quality. These parameters include: open circuit voltage, short-circuit current, series resistance, maximum power point, the fill factor, efficiency. Under the influence of solar radiation on the cell, on its open terminals open circuit voltage occurs, otherwise known as load voltage (current is zero). Joining the load (ESR) R_S to these terminals, will close the circuit, the current flow, depending on the RS. The highest value of current at $R_S = 0$, is called a short-circuit current I_{SC} . These parameters are indicated on the current-voltage characteristics (Fig. 1). Another important parameter is the maximum power point MPP , it can be defined as a rectangle with a maximum surface area, based on the coordinate axes and vertex belonging to the characteristics, the apex of which determines the maximum power, rating of P_{MPP} cells. U_{MPP} power and I_{MPP} current for the maximum power point are the ratings of the cell. MPP point can also be determined by the characteristics of the load (Figure 1), also known as the fixing. An important quantity determines the fill factor FF also known as the utilization rate of the cell. It reaches a value of 1 when the current-voltage curve is a rectangle with sides of the U_{OC} and I_{SC}. This situation describes the perfect conditions. The fill factor can be expressed by the following equation:

$$FF = \frac{\text{surface area B}}{\text{surface area A}} = \frac{P_{MPP}}{U_{OC} I_{SC}} = \frac{U_{MPP} I_{MPP}}{U_{OC} I_{SC}} \tag{1}$$

where: P_{MPP} maximal (nominal) cell power, U_{OC} open cell voltage, I_{SC} short circuit electric current, U_{MPP} and I_{MPP} voltage and electric current in the point of maximal power.

The efficiency of the cell (module) is the ratio of the power generated electricity, P_{MPP} to power of incident light radiation, P_{in}:

$$\eta = \frac{P_{MPP}}{P_{in}} = \frac{U_{MPP} I_{MPP}}{E \cdot s} \tag{2}$$

where: E – radiation intensity [W/m^2], s – surface of examined module [m^2].

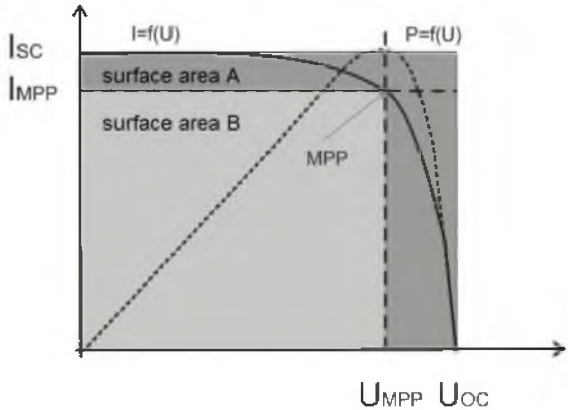


Fig. 1. Current-voltage characteristic and load characteristic (power)

An important parameter that affects the yield of electricity is the operating temperature of the cell. Manufacturers usually provide the ratings for a temperature of 25 °C and a density of radiation 1000 W/m^2. For temperatures above 25 °C, each cell temperature increase causes a decrease in maximum power, and for temperatures below 25 °C any decrease in cell temperature causes an increase in maximum power (Fig. 2). Taking into account the negative impact of the increase of the cell temperature on the efficiency of the cell temperature, appropriate cooling and ventilation modules should be provided. This task is performed by the appropriate assembly of modules that provides free air flow by installing [1, 3, 4].

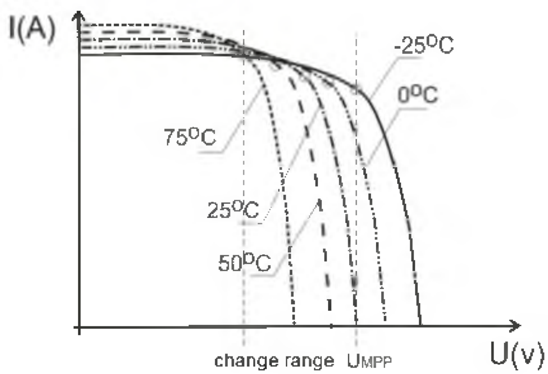


Fig. 2. The impact of cell temperature on its efficiency

3. Chosen elements of designing photovoltaic power plants

An important aspect of the design of the photovoltaic modules is their location towards the solar radiation. Depending on the geographic location it is necessary to select properly the optimal tilt angle of the modules towards the surface (angle α) and setting them in the southern direction. Photovoltaic module receives the greatest amount of energy when the sun's rays fall perpendicularly to its surface. A slight deviation of the module from the south direction (angle β) has little effect on the efficiency of the installation, however, is associated with decreased energy yields. The optimal distance between the modules can be determined from the equation (Fig. 3):

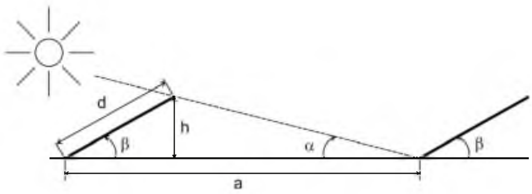


Fig. 3. Selection of intervals between the rows of photovoltaic modules

$$a = d(\cos\beta + \sin\beta\cos\alpha) \tag{3}$$

where: a – distance between the beginnings of further rows of modules, h – height of module edge from the ground, d – module length, α – sun incindence angle, β – inclination angle to surface.

There are two basic ways to connect modules, in series and parallel. Series connection increases voltage in proportion to the number of modules, such as for three modules three times (Fig. 4). It should be noted that the combined components which make up the chain must have the same parameters, particularly the same type and the same currents. Current degradation of one of the components will affect the entire chain. Parallel connection increases the current in proportion to the number of modules.

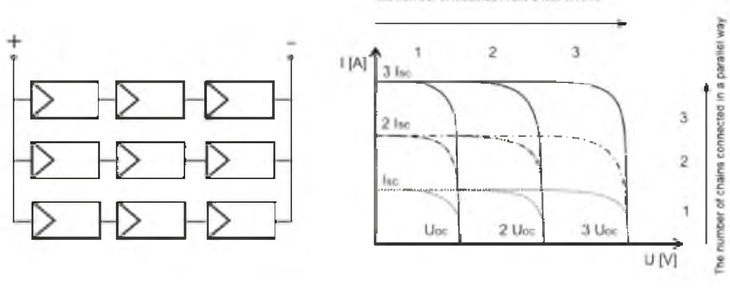
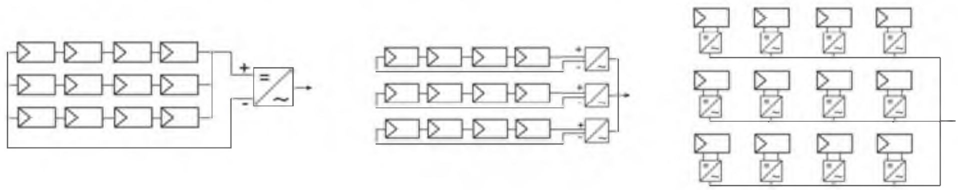


Fig. 4. Series-parallel connection of photovoltaic cells (modules)

Parallel connection of several serial chains is possible only for an identical number of modules in series. Photovoltaic module provides a constant current, so it is necessary to use the inverter. It is characterized by several parameters: power, operating voltage range, starting voltage, the minimum input voltage, maximum input voltage, maximum voltage (in the MPP point), the amount of input entries (MPP trackers). There are three basic types of turning on the inverters (Fig. 5): central, serial (string) and built-in microinverter in module [1, 3, 4].



a b c

Rys. 5. Inverter types: a) central, b) string, c) microinverter built in the module

4. Photovoltaic power systems modeling

Simulation modeling is an increasingly popular method of assessing the improvement of processes efficiency, and allows pre-parameter optimization of energy systems in order to achieve maximum efficiency. The ever-growing number of products on the market of software used for simulation and analysis of various kinds, makes simulation capabilities vast. Planning a photovoltaic system is a complex process in which a number of different factors must be taken into account, such as the choice of the type of the module, and the inclination angle of the modules, the level of radioactivity, the choice of the most suitable inverter, etc. Beside commercial software, in recent years, interesting free programs for designing photovoltaic system have been created. They include: RETScreen, Lynx Planner SMA Sunny Design.

RETScreen allows for making decisions in the management of clean energy. It is a free software made available by the Government of Canada. RETScreen allows you to evaluate the potential energy projects in the field of renewable energy, energy efficiency or cogeneration systems. The analytical tools in the RETScreen are fully integrated with database of products, projects, and a database of hydrological and climatic conditions [7].

Sunny Design is a software for planning and designing of photovoltaic power plants. Sunny Design lets you design an installation which supports the process of selecting equipment for PV systems [9].

The Lynx Planner by Danfoss is another tool to support the process of designing a PV installation. This software has a user friendly interface that with the introduction of a minimum amount of data can analyze and present an optimal photovoltaic system [8].

An interesting solution for the preliminary analysis of photovoltaic systems is the program PV PHIL program. It is a free software that is available directly on the website of the manufacturer, which can be used without the program installation. [6].

5. Energy and economic analysis of photovoltaic power plant

In order to compare the capabilities of the software, the photovoltaic power plant project with a capacity of approximately 10 kW, mounted on the roof of the house has been analyzed (Table 1). Total cost of the project was set at PLN 83,500. It is assumed that the purchase cost of PV panels, inverters, mounting structures and wiring is about 80% of total investments. Preparation of the investment is approximately 3% of the cost, installation accounts for nearly 12% of the cost, and the annual operating cost is about 2%.

Table 1. Comparison of the basic parameters of individual programs

Program / Parameter	Sunny Design	Lynx Planner	PV Phill	RETScreen
Number of modules	42	44	40	40
Power [MWp]	9,66	10,1	9,2	9,66
Annual energy output [kWh]	9185,4	9488	8919	10680
Efficiency ratio [%]	83	81,9	-	-
Energy output [kWh/kWp]	951	938	969	-
Other abilities	Selection of wire section. Selection of localisation and meteo parameters.	Selection of localisation and meteo parameters.	Selection of Google Maps localisation. Financial analysis.	Financial analysis.

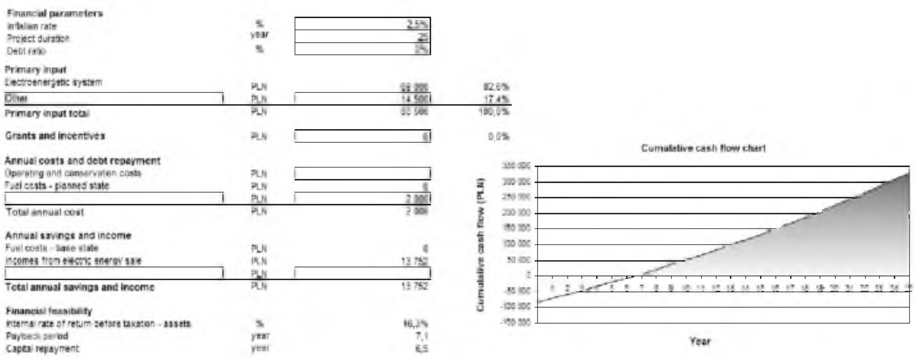


Fig. 6. Financial parameters obtained in Retscreen

Due to analysis of the RETScreen program the economic aspect of the proposed project can be evaluated. Based on the assumed parameters, costs and energy prices, including the possible use of a Feed In Teriff terrif (1.30 PLN/MW) payback period of sustained investment is 7.1 years (Fig. 6).

6. Conclusions

Although the possibilities of the development of the photovoltaic market in Poland are limited, it is advisable to pay attention to the possibility of using solar energy in terms of direct benefit. There are environmental, economic and social benefits. Poland is obliged to reduce CO_2 emissions into the atmosphere, thus increasing the share of renewables in primary energy structure, directly contribute to lowering emissions.

Based on the analysis it can be seen that the basic parameters of the calculations obtained from several programs do not differ significantly from each other. And the use of open software lets you design a photovoltaic system. But if a rate of Feed In Teriff for the price of energy was not favourable, payback of such an investment would be longer than the assumed lifetime of photovoltaic modules.

Although photovoltaics will not be a competition for fossil energy for a long time, its participation should gradually increase, leading in the future to the change of energy production structure and making energy friendly to humans and the environment.

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