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INVESTMENT PROFITABILITY ANALYSIS OF AN ON-GRID PHOTOVOLTAIC SYSTEM

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Abstract *The potential of the solar energy sector is starting to become increasingly important. The possibility to produce electrical power for household needs, as a result of an investment in photovoltaics is gaining popularity, and storing its surplus in a power grid and settlement of its consumption on the basis of an annual balance, allows to limit electricity bills to the minimum. The implementation stage, which promotes investing in solar renewable energy for own household needs was introduced by the new Act on RES, promoting the prosumer On-Grid system. The paper focuses on presenting the analysis of profitability of installing photovoltaic On-grid systems.*

Keywords: photovoltaic systems, On-Grid systems, Renewable Energy Sources

ANALIZA OPŁACALNOŚCI INWESTYCYJNEJ INSTALACJI FOTOWOLTAICZNYCH W SYSTEMIE ON-GRID

Abstract *Potencjał sektora energii słonecznej zaczyna nabierać coraz większego znaczenia. Możliwość produkcji energii elektrycznej na własne potrzeby, dzięki inwestycji w fotowoltaikę zyskuje coraz większą popularność, a magazynowanie jej nadwyżek w sieci energetycznej oraz rozliczanie jej zużycia na podstawie rocznego bilansu umożliwia ograniczenie rachunków za prąd do minimum. Fazę implementacji, promującą inwestowanie w słoneczną energię odnawialną na potrzeby własnych gospodarstw zaimplementowała nowa ustawa o OZE, promująca system prosument w systemie On-Grid. W artykule skupiono się na przedstawieniu analizy opłacalności inwestycyjnej instalacji fotowoltaicznych w systemie On-grid.*

Słowa kluczowe: systemy fotowoltaiczne, systemy On-Grid, odnawialne źródła energii

Introduction

Photovoltaic On-Grid systems consist of solar panels connected to a device called an inverter, which enables the production of electricity deriving from the sun, and transferring it to the power grid in the form of 230 V voltage. Such systems are becoming more popular in Poland, especially in the form of photovoltaic micro-systems, which enable the production of electricity for personal use.

The On-Grid technology allows storage of surplus of the produced energy in the power grid owned by ZE (Power Distribution Company), thanks to what, batteries, which are characterised by low efficiency, are not used for its storage. Storing surplus produced energy and using it in the case of a production shortage make possible to return the expenditure associated with this investment after about 8 years of use. Of course, the primary condition which needs to be satisfied, is an optimally designed system, which should provide functional self-sufficiency of a household. In addition, the manufacturers of photovoltaic panels guarantee their efficiency for a period of 25 years, without special maintenance and the ever-growing electricity prices makes the On-Grid systems a definitely cost-effective investment.

1. Photovoltaic cells

Photovoltaic cells are in the form of wafers and are built mainly from mono or polycrystalline silicon with a different crystallization degree. Connected together, they form photovoltaic modules, which are used to convert solar radiation energy to electricity. Their mode of operation is similar to that of a photocell, namely, under the influence of light and as a result of electron movement, a difference of potentials is created and converted into power. This conversion is called the photovoltaic phenomenon. This effect was identified in 1839 by a French physicist and physical chemist, Alexander Bacquerel [16].

The phenomenon is possible thanks to a silicon plate with a semi-conductor junction, so-called P-N, where, under the influence of photons with energy greater than the width of the band gap of the semiconductor (width of the energy gap where the electrons are scattered on the atoms), the electrons move towards the N area and then combine with positive charges [2]. The cells, where the basic construction element is mono or polycrystalline silicone with additives, in the form of a 0.2 mm thick wafer, belong to the, so-called, first generation cells.

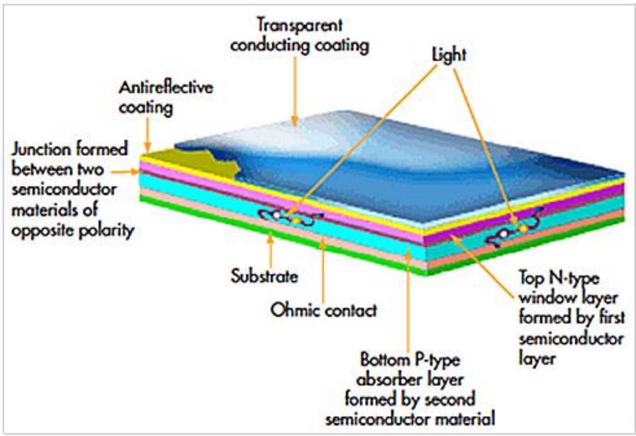

Fig. 1. A diagram of a thin-layer photovoltaic panel [5]

As literature studies indicate, the monocrystalline cells are characterised by the highest efficiency, reaching up to 19–22%, but due to being made from monocrystal, they are also characterised by a high price per watt of installed capacity. A large coefficient of power decrease together with temperature increase is characteristic for this type of cells. As studies show, polycrystalline cells are made from silicone polycrystal, are characterised by high efficiency, however, lower than monocrystalline, and a high power decrease together with temperature increase. Calculated per watt of installed capacity, they are cheaper than the previous ones by around 10–15%.

The second generation of photovoltaic cells is also based on the P-N junction, for the construction of which another semiconductor material is used: cadium telluride (CdTe), a mixture of copper, indium and selenium – CIS or copper, indium and gallium (CIGS). The abbreviations come from the basic components of the module. These cells are characterised by a lower price due to the used thin layer of the photon absorbing material, however, their disadvantage is a significantly lower efficiency, reaching 6-15%. There is also a third generation of cells available on the market, which differs from the rest with a lack of the P-N junction and the cells being made with the use of polymers. They are characterised by low efficiency and significantly shorter service life. The colours of photovoltaic cells may come in various shades of navy blue and depends mainly on the degree of use of semiconducting materials and the manufacturing technology.

2. On-Grid network system

There are many concepts of photovoltaic system designs. The most popular are: the grid system, the so-called On-Grid, island system, so-called Off-Grid or the hybrid system.

The island or hybrid solutions require the installation of special batteries, with the aim to store surplus. These systems are used in cases, where it is impossible to connect the system to the power grid. The grid system is the most popular solution, possible in a situation, where energy surplus, in the context of the act on renewable energy sources of 22/6/2016, can be stored in the grid. In light of the new act, the final consumer, called the prosumer, may be a person who purchases electricity under a comprehensive contract with a Power Distribution Company, but also produces electricity from renewable sources in own microsystems, for personal use, not associated with the conducted business activity, governed by the act on the so-called freedom to conduct business [1].

Electricity surplus, produced by a photovoltaic system, as per the new act, can be stored in the grid and the total settlement is based on an annual balance with the Power Distribution Company, meaning the electricity introduced to the grid not earlier than 365 days prior to the day of taking the settlement reading in a given settlement period.

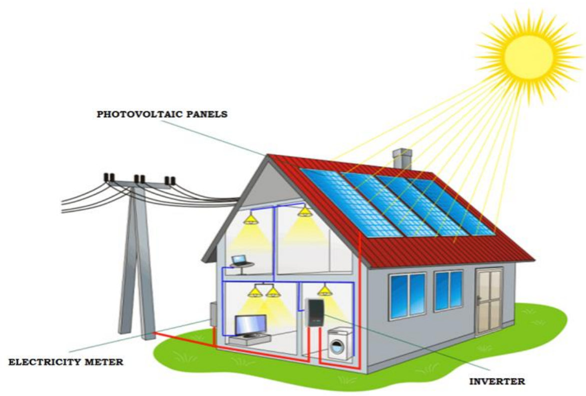

Fig. 2. Block diagram of a On-Grid photovoltaic system

The settlement of the amount is conducted on the basis of readings from metering-billing devices for a given microsystem in such a way, so that the amount of electricity consumed and stored by a prosumer is settled after is combined balance. The surplus of stored energy shall become the property of the Power Grid Operator from the beginning of the new settlement period. It is worth mentioning, that the production and storage of electricity in own systems is not a provision of services, within the meaning of the Act on the goods and services tax, therefore, it does not require running a business, within the meaning of the act on the freedom of conducting a business activity [1]. The seller settles the amount of electricity introduced by a prosumer to the power grid in relation to the power consumed from the rid at a 1:0.8 ratio – for systems with a combined power of not more than 10 kW and 1:0.7 in other cases.

As the performed analyses show, storing energy with batteries, as is the case with Off-Grid and island systems, also does not guarantee 100% reception (around 85% in total conversion), thus, in light of the above, the On-Grid system seems to currently be the best possible solution.

3. Investment profitability in Poland

The prosumer system, which currently is the only economically viable solution, assumes that the energy surplus generated in the spring-summer period are sent to the grid, in order to recover them at night or in the autumn-winter period, when the system does not generate enough electricity. Such a solution should enable total reduction of electrical bills, provided of course, that the photovoltaic system is correctly designed, with particular emphasis on the selection of the number of panels in relation to the amount of annual energy consumption.

In many European countries (unfortunately, not Poland), the price of electricity derived from renewable sources and resold to Power Distribution Companies is much higher than the price of energy available from the grid, therefore, the sales of energy in those countries is much more profitable than using it for own needs. Poland is located in an area of energy yields similar to Germany, a leader in the photovoltaics field in Europe (China is the world leader). The insolation conditions vary depending on the regions of the country. Average insolation in Poland is about 1000 kWh/m^2/year. Fig. 3 shows how it differs in particular regions of the country.

Fig. 3. Average insolation in Poland [14]

Apart from the satisfaction of the possibility to generate green energy, the greatest profit is obtained with an optimally matched system, i.e., one that will allow us to use 100% of its production for own needs within a calendar year. Average solar energy values and short-term power which can be utilized in the city of Opole are shown in Tab. 1 and Fig. 4.

Table 1. Insolation over individual months of the year for the city of Opole

Month	kWh/m^2/month
I	27.1
II	43.6
III	79.67
IV	114.8
V	152.6
VI	145.4
VII	158.2
VIII	132.2
IX	89.3
X	55.2
XI	28.9
XII	22.2

The results obtained for the city of Opole were compared with average monthly insolation for cities located in different parts of the country: northern: Szczecin, Gdańsk, central: Warsaw, western: Wrocław, eastern: Rzeszów and southern: Kraków (Fig. 5) [9]. As the performed comparative analysis shows, the average insolation for Opole, does not differ from the remaining parts of the country, so it can be said that investments in photovoltaic systems in Poland are profitable in each of its regions.

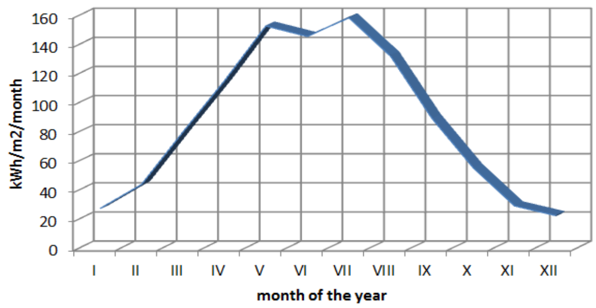

Fig. 4. Insolation over individual months of the year for the city of Opole

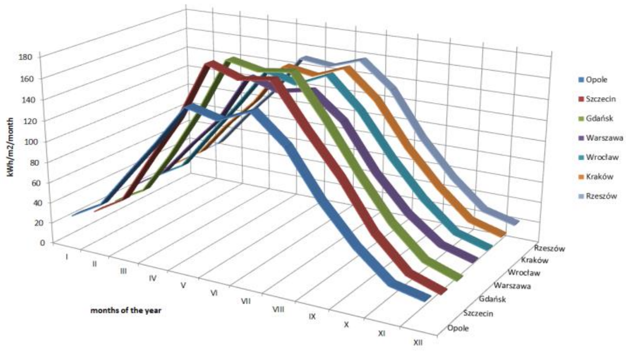

Fig. 5. Average monthly insolation in selected cities in Poland

A significant problem in energy generation is noticeable in the first three months of the year and the last three months, where a short day and a slight amount of insolation make overproduction from March to September and the storage of energy possible. Therefore, during that period, a correctly designed system should produce and store such an amount of electricity, which would cover the production shortages during the other months.

The current share of RES (Renewable Energy Sources) in the entire power economy of our country is, according to various sources, around 11%, whereas, in 4 years it is supposed to reach 15% recommended by the EU. According to the data published by the Central Statistical Office (GUS), the share of consumption of energy coming from RES in Poland in 2016 is similar to that of 2013 at around 11.5%, which is a major threat to achieving the recommended 15%. On the basis of that data, the estimated possible yield in 2020 may be about 13–13.5% [10].

As the above data shows, Poland has only four years to make up for that backlog, thus, it can be concluded that investments in photovoltaic systems, wind turbines or other renewable energy sources are insufficient. The delays may result in the failure to achieve the recommended plans, which could expose our country to liquidated damages from the EU (European Union). The data of the Polish Society of Power Transmission and Distribution indicated that over 2.5 thousand solar power plants have been connected to the five of the biggest Power Distribution Companies (PGE, Tauron, Enea, Energa, Innogy).

In order to reach the goal of 15% set by the EU, it is going to be necessary for Poland to open itself to the RES development in the upcoming years, with particular emphasis on wind and photovoltaic energy. The currently available power potential is able to generate a little more than over 20 TWh of energy from RES [10].

In order to meet the required 15% general share of RES, it would have to generate over 30 TWh. The RES share in the power economy in EU countries is gradually growing, while the coal consumption for power generation is decreasing. Compared to Great Britain – 11% of its generated energy came from wind farms – an increase of 1.5% in relation to the previous year, while in German, the increase of the same source in relation to 2014 was over 4% [11].

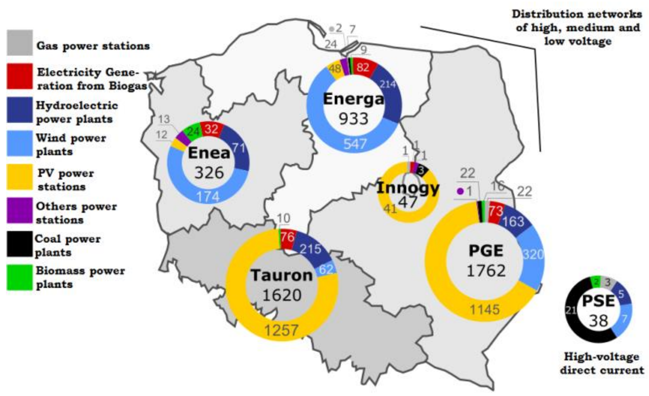

Fig. 6. Number and type of power plants connected to the power grids of individual operators [4]

Unfortunately, it is completely different in Poland, because, as market analyses indicate, coal - a non-renewable energy source, will for a long time still be a dominating fossil fuel used in the power production process. A confirmation of that may be the investments in coal fired Power Plants.

For example, the Opole Power Plant - investment value of over PLN 11.5 bn, expected completion date for unit 5 – mid-2018, unit 6 – March 2019.

The predicted maximum emission parameters of the units for: sulphur dioxide (SO_2) are to be 100 mg/Nm^3, nitrogen oxides (NOx) – 80 mh/Nm^3 and dust 10 mg/Nm^3 – through using two, four-zone ecofilters per each boiler. The units were designed to meet the requirements of BAT *Best available technology* used to determine the amount of pollution emissions for larger industrial plants in the EU [3].

Given the above and the fact that works on increasing the efficiency of coal power are ongoing, an elastic combination of non-renewable and renewable technologies would be the most effective solution.

4. Poland and the countries of the European Union and the world

More and more often a question arises, which addresses the issue of Poland catching up with the EU countries, which successively pursue innovations in the power sector. From the point of view of a coal-oriented politics, it might seem troublesome, even unlikely, and the constant subsidies to unprofitable mines might lead to an increase of prices for electricity in our country.

Poland is in the part of the continent, where the solar resources are similar to those in other countries. Average insolation calculated in kWh/m^2/year is over 1000 kWh/m^2/year. Despite the lower insolation in the northern part of Europe, from 900 to 100 kWh/m^2/year, the photovoltaic equipment is successfully used also there (Fig. 7). The most favourable conditions for photovoltaics are in the area of the Mediterranean basin, where the average insolation is up to 2000 kWh/m^2/year [8]. RES are in different advancement stages in individual European countries. The leaders of green energy are, primarily, Sweden, Lithuania and Finland, where the share exceeded 30%. Holland, Malta and Luxembourg are at the other extreme, with the RES share below 5% [13].

Dominant global ecologic trends are also worth mentioning, where the main feature is limiting the emission of pollutants into the atmosphere. Also in Poland, during the winter time in particular, an increase in air pollution could be felt. Smog forming over the cities was mainly caused by burning in furnaces, with the primary combustion component being coal, also the heavily contaminated one, which, when burned, is accompanied by the exudation of sulphur dioxide, nitrogen oxide and dust.

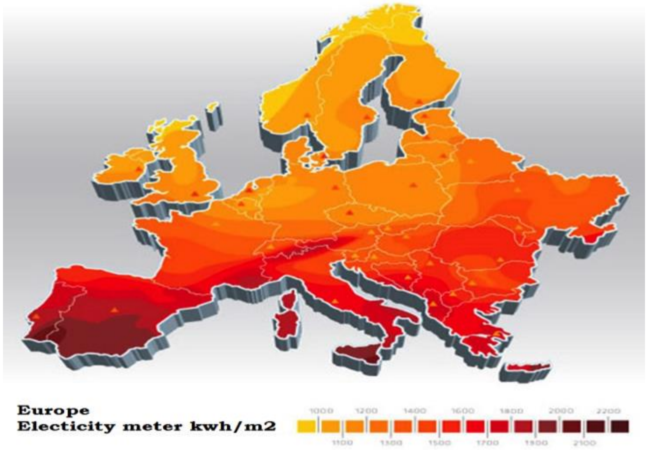

Fig. 7. Average insolation in Europe in kWh/m^2/year [8]

5. Practical implementations

The implementation stage, which promotes investing in solar renewable energy for own household needs was introduced by an act of 22 June 2016 on amending the Act on renewable energy sources, promoting the prosumer On-Grid system. The potential of the solar energy sector in our country is becoming more and more important. It is becoming possible to introduce photovoltaic systems to the Polish photovoltaics market, which supply household with electricity for own needs.

The selection of a grid system in the On-Grid version, where the electricity surplus will be stored in the grid, depends on the demand for power and energy, and the roof area available for installation. Installation on flat roofs or surfaces, due to the used inclination angle becomes a little complicated. Proper intervals must be kept in order to avoid shading of the system. The installation of a photovoltaic system also requires the replacement of the traditional electricity meter with a bidirectional meter. It is usually installed in place of the existing one and does not require any change to the electrical system.

6. Conclusions

Supporting RES is a priority objective of the Union, of which Poland is a member state. A fact important to be emphasised is that we are no longer doomed to the monopoly of Power Distribution Companies and investing in RES is becoming more financially beneficial, currently only for own needs, since a properly matched PV system may minimize our electricity bills to the minimum. The temperature of the environment in which the cells operate has a high impact on their efficiency – at high temperatures, the losses may reach even 0.5%/°C. In comparison to the traditional and commonly available mono and polycrystalline cells, the difference in module efficiency is, respectively, 20% and 16%. The price of monocrystalline cells is higher compared to the polycrystalline ones by about 30%–35%, which strongly impacts the selection of a system in terms of efficiency and economy. An indicative cost of a photovoltaic system for an annual electricity consumption around 4500 kW/year is currently PLN 30 000 (data for February 2017).

Literature

[1] Act of 22 June 2016 on amending the Act on renewable energy sources and other acts, item 925, http://dziennikustaw.gov.pl/du/2016/925/1 (available 15.01.2017).
[2] Chopra K. L., Paulson P. D.: Thin-Film Solar Cells: An Overview, Photovoltaic Laboratory, Centre for Energy Studies, Indian Institute of Technology Delhi
[3] Data Polish Energy Group Mining and Conventional Power Generation S.A., https://www.pgegiek.pl/ (available 08.01.2017).
[4] Data PTPiRE,WysokieNapiecie.pl, 2016
[5] Dirjish M.: What's The Difference Between Thin-Film And Crystalline-Silicon Solar Panels? Electronic Design, http://electronicdesign.com/power-sources/what-s-difference-between-thin-film-and-crystalline-silicon-solar-panels (available 10.01.2017).
[6] Grid photovoltaic systems ENLAB SMART HOME – materials belonging to EnLab Nowy Sącz, http://enlab.pl/elektrownie-fotowoltaiczne/domu/rozwiazania/ (available 18.01.2017).
[7] Huld T., Müller R., Gambardella A.: A new solar radiation database for estimating PV performance in Europe and Africa. Solar Energy 86/2012, 1803–1815.
[8] Insolation in Europe, http://www.ogniwafotowoltaiczne.pl/pl/energiasloneczna/49-energia-soneczna (available 09.01.2017).
[9] Insolation in Polish cities, http://www.ogniwafotowoltaiczne.pl/pl/energiasloneczna/50-naslonecznienie-w-polskich-miastach (available 12.01.2017).
[10] Polish Wind Energy Association (PSEW), art. Without wind, Poland will fail to meet EU requirements – PSEW analysis regarding annual RES targets, http://psew.pl/2017/01/09/bez-wiatru-polska-spelni-unijnych-wymagan-analiza-psew-dotyczaca-rocznych-celow-oze/ (available 18.01.2017).
[11] Renewable Energy in Europe 2016. Recent growth and knock-on effests. European Environment Agency Report 4/2016.
[12] Renewable Energy Portal, Solar energy in Europe, Insolation in Polish cities, http://odnawialnezrodlaenergii.pl/ (available 17.01.2017).
[13] RES share in Europe is growing too slowly. Article by Enrad, https://enerad.pl/aktualnosci/w-unii-europejskiej-udzial-oze-rosnie-za-wolno/ (available 22.01.2017).
[14] Solar radiation and photovoltaic electricity potential country and regional maps for Europe, http://re.jrc.ec.europa.eu/pvgis/ (available 10.01.2017).
[15] Šúri M., Huld T.A., Dunlop E.D. Ossenbrink H.A.: Potential of solar electricity generation in the European Union member states and candidate countries. Solar Energy 81/2007, 1295–1305.
[16] Wróblewski A.: Raz dobrze, raz źle. Wiedza i Życie, 2011.

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