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Economic analysis of stationary and spatially optimized photovoltaic systems for Polish climatic conditions

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The paper presents the economic aspect of use two - axis Sun tracking systems compared with stationary units in photovoltaics on the basis of own annual measurements of electrical energy for local urban conditions. The results were scaled to maximum power of 10 kW_p. Electricity consumption by positioning system and maintenance costs were included and estimated payback period of investment for different variants of settlement of produced energy, taking into account own financing, banking and preferential subsidies under the Prosumer program from the National Fund for Environmental Protection and Water Management, was calculated.

KEYWORDS: tracking system, economic balance, photovoltaics, payback time

1. Introduction

The economic aspect of using and installing various types of photovoltaic systems is often a complex problem and its solution requires taking into account type of installation and its power, available space, module technology, price of electricity and yearly growth and support from state or local government. Stationary systems consisting of PV modules installed with one annually fixed inclination and azimuth angle have the highest yield in a specific, short period of time.

The use of tracking plane as a place of installation of PV modules gives possibility to increase electricity production about 40 % - 45 % for 2 - axis tracking systems [1, 2, 3, 7, 8, 11, 13] and approximately 30 % in case of one - axis trackers [4, 9, 10, 12]. In addition increased cost of maintenance and possibility of failure must be taken into account. Currently, estimated amount of installed power in solar energetics exceed 30 GW.

Next to the price of photovoltaic system components such as PV modules, inverters and supporting structures [6] a significant impact on the economic aspect of the solar systems has proposed by the state model of support in form of feed-in-tariff rates (currently 32 countries have feed-in-tariff) for unit of electricity produced from renewable sources of energy, preferential prices of repurchase or subsidies including low-interest loans.

All these components affect the growth in interest in renewable energy sector. They give possibility to reduce the emission of carbon dioxide and help

achieve declared 15 - percent contribution of renewable sources in total country energy balance to 2020 year.

According to the version 2.0.1 of the Renewable Energy Sources draft law dated 04.10.2012 [15], Ministry of Economy predicted the following 15 - years rates per unit of electricity for micro - and small photovoltaic installations valid at least to 2027:

- photovoltaic installations with maximum power up to 10 kW_p installed on the building-1,30 zł/kWh,
- PV installations with maximum power in the range of 10 kW_p - 100 kW_p installed on the building or installations up to 10 kW_p mounted outside the building - 1,15 zł/kWh,
- photovoltaic installations with power between 10 kW_p - 100 kW_p installed outside the building - 1,10 zł/kWh. In previous version of RES project one feed – in - tariff rate for solar and wind energy equals 1,10 zł/kWh for power up to 100 kW was expected [14].

Project 4.1 dated 31.12.2013 showed that there is no chance to introduce feed – in - tariff rates in Poland because of expected rapid growth in interest RES installations like it took place in German and Czech Republic market in 2009 - 2010, when Czech Republic became third world largest country in new power connected to the grid. This changed dramatically in 2010 when Power System Operator has expressed opposition to new power plants being attached to the AC grid, while distributors such CEZ reduced the number of terms of connection and set new requirements like 3 - phase inverters for installations with power greater than 3,5 kW [18].

The new version of RES project dated 28.03.2014 with signature 6.3 confirmed resignation of Polish government from the idea of guaranteed rates introducing the concept of prosumer energetics as a local electricity generation in conjunction with own consumption in place of generation and resale resulting surplus to the grid. The main disadvantage of this solution is low price of electricity from photovoltaic conversion representing 80 % of the average electricity price from previous year which makes 0,156 zł/kWh.

In case of energy generation in majority to the AC grid with proposed rates one should be noted that investment in photovoltaics is not suitable for investors looking for quick return of initial costs and serious profits in a short period of time. It seems to be necessary to consider different variants of settlement of produced electricity from solar energy or combinations like partial resell and use or accumulation of produced electric energy.

2. Settlement of electricity from PV systems

Economic analysis was carried out for installation with maximum power 10 kW_p - ten two - axis Sun trackers compared with fixed installation placed on supporting structures with the same power. A single system presented in [5] is the actual object of study.

Results of annual measurements of electricity from 06.2013 - 06.2014, obtained using prepared stands located on the roof of Poznan University of Technology Faculty of Electrical Engineering, were used in analysis. In case of the stationary system electricity produced per year is approximately equal to 9361,9 kWh, while using two - axis system, taking into account energy consumption for control and supply needs (nearly 13 %), 11524 kWh.

Annual decrease of modules power performance and increase of electricity price equals 0,7 % and 5 %. Estimated cost of maintenance for fixed and 2 - axis tracking systems was set at the level of 500 zł and 700 zł including inflation. During the warranty period works are mainly associated with cleaning the surface of the modules. No specialized companies obliges owners of installations to deal with this problem.

Analyzing the profitability of photovoltaic installations, in both stationary and tracking configuration, different possibilities of settlement of produced energy must be considered:

- 25 % of produced electric energy is transferred to the AC grid (0,156 zł/kWh profit), 50 % is used for water heating generating profits to an equivalent gas heating, 25 % creates own consumption,
- total sale of produced electric energy to the AC grid according to expected feed – in - tariff rates (1,30 zł/kWh) for roof type installations up to 10 kW,
- annual usage of 3,000 kWh electric energy by 150 m^2 single - family house and the sale of surplus electricity to the AC grid (0,156 zł/kWh),
- sale of electric energy to AC grid according to feed – in - tariff rates (1,30 zł/kWh) and financing the total investment using mortgage credit with equal installments at the level of 4,5 % per year for a period of 15 years,
- annual usage of 3,000 kWh electric energy by 150 m^2 single - family house and the sale of surplus electricity to the AC grid (0,156 zł/kWh), financing 40 % of the investment with Prosumer program from National Fund for Environmental Protection and Water Management using low - interest 1 % per year preferential credit for a period of 15 years,
- sale of produced electric energy with rate 1,30 zł/kWh (based on RES law project dated 04.10.2012) and financing 40 % of the investment with Prosumer program in combination with low - interest preferential credit,
- total produced energy by fixed and 2 - axis tracking system is used for own consumption by individual power consumer. Subsidies from Prosumer program are used.

Variant no 1

Electricity generated by the photovoltaic system (stationary and dual - axis) will be used primarily to cover consumer needs, while 25 percent will be sold to

the AC grid - 0,156 zł/kWh (according to changes in RES law project from 28.03.2014). The usage of produced electric energy will replace gas heating generating additional profits approximately equal to 0,30 zł/kWh. Distribution of produced electric energy by photovoltaic systems is shown in Figure 1.

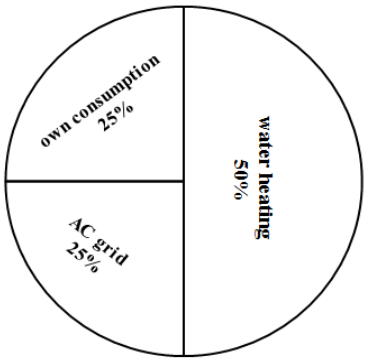

Fig. 1. Percentage distribution of produced electric energy

According to performed analysis a graphical interpretation of results was made and a payback time for both investments was calculated.

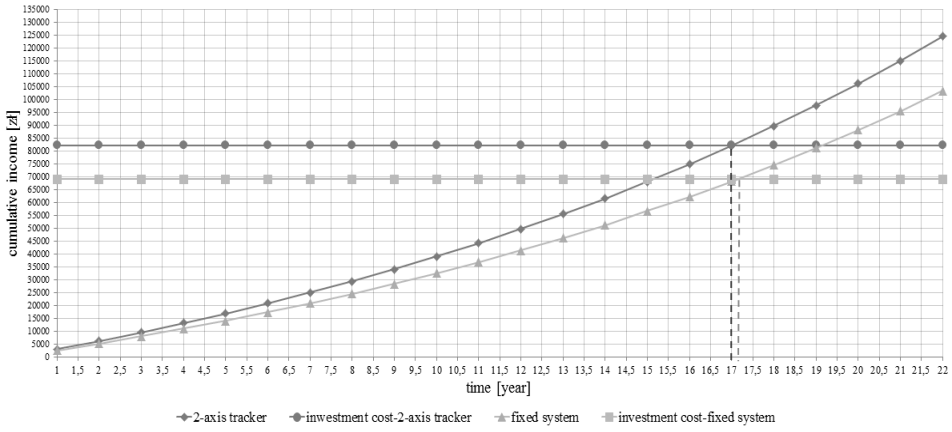

Fig. 2. The value of the cumulative income resulting from the method of settlement in relation to the costs of investment

Variant no 2

The main part of produced electric energy, according to RES law project dated 04.10.2012, will be transferred to the AC grid with rates of repurchase equal to 1,30 zł/kWh for power up to 10 kW.

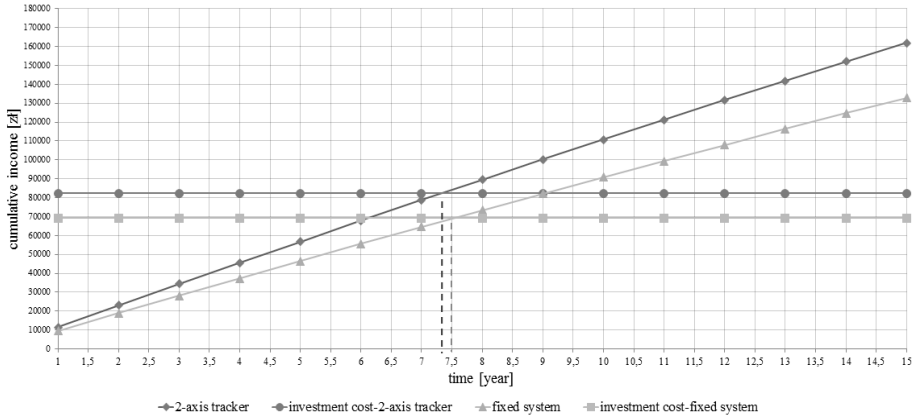

Fig. 3. The value of the cumulative income resulting from the method of settlement in relation to the costs of investment

Variant no 3

Electric energy produced by both photovoltaic systems covers the needs of a 150 m^2 single - family house - 3,000 kWh per year. The rest of the electric energy is transferred to the AC grid with a rate equal to 0,156 zł/kWh.

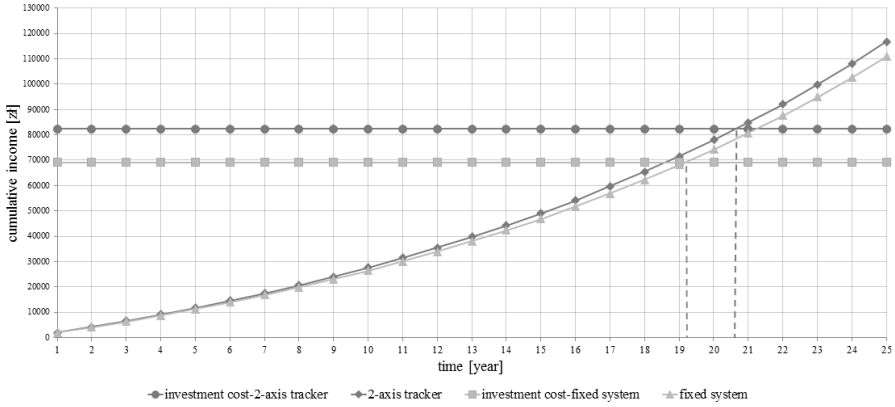

Fig. 4. The value of the cumulative income resulting from the method of settlement in relation to the costs of investment

Variant no 4

Financing the investment is realized using a mortgage loan with an annual interest rate of 4.5 % for a period of 15 years. For microinstallations with maximum power up to 10 kW_p settlement of produced electric energy is based on rates equal to 1,30 zł/kWh (according to RES project predictions from 04.10.2012).

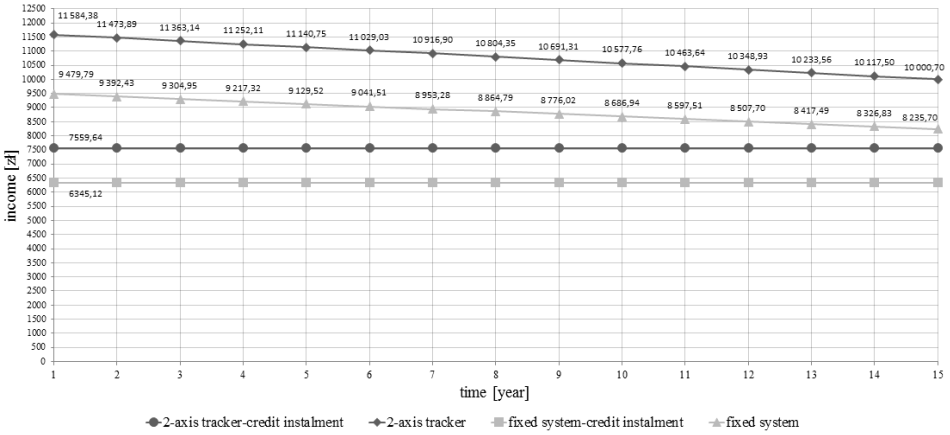

Fig. 5. The value of the income resulting from the method of settlement in relation to the costs of mortgage credit in 15 years period of time

Variant no 5

Settlement of produced electric energy consists of using 3000 kWh per year for 150 m^2 single - family house (20 kWh/m^2). The rest of the electricity is transferred to the AC grid with rate equal to 80 % of the average price of electric energy from previous year. An investor participating in the Prosumer program uses the 40 % financing, while the remaining part of the investment is financed using low - interest credit for 15 years.

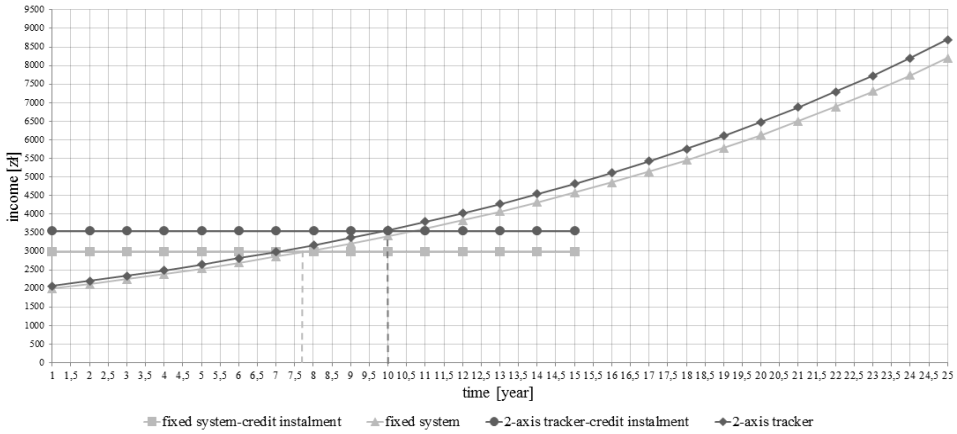

Fig. 6. The value of the income resulting from the method of settlement in relation to the costs of preferential credit in 15 years period of time (credit period) and 25 years (operation period)

Variant no 6

Electric energy generated by both photovoltaic systems is sold to the AC grid with rate 1,30 zł/kWh (based on RES law project dated 04.10.2012). In 60 % investment is financed using preferential credit and in 40 % from Prosumer program.

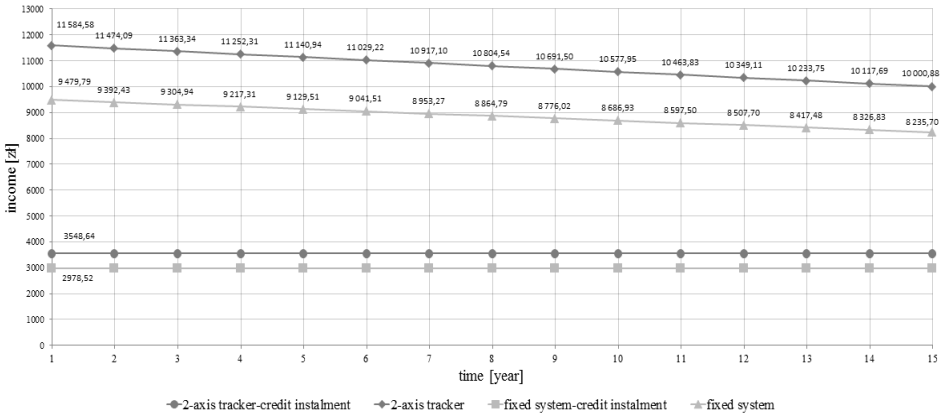

Fig. 7. The value of the income resulting from the method of settlement in relation to the costs of preferential credit in 15 years period of time

Variant no 7

The case includes the situation in which all the produced electric energy by fixed and tracking system is used for own domestic needs saving 0,56 zł/kWh (average price of electricity in 2014, Enea operator, Poznan, G11 tariff).

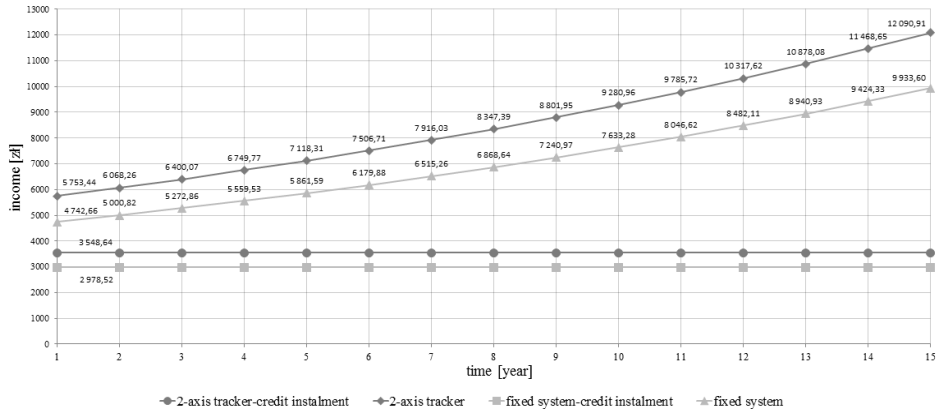

Fig. 8. The value of the income resulting from the method of settlement in relation to the costs of preferential credit in 15 years period of time

3. Conclusion

- Profitability of investing in photovoltaics depends on the value of produced electric energy, insolation, the number of sunny hours per year, thermal parameters like nominal operating cell temperature NOCT, correctness off realized construction works or technology of used PV modules, whose parameters like open circuit voltage temperature coefficient, power tolerance, the efficiency at low radiation power density ($\leq$ 200 W/m^2) and the quality of silicon solar cells (on the basis of fill factor coefficient, visual or EL tests) influence on annual energy gain.
- Important meaning in case of PV sector has proposed and implemented by the Ministry of Economy, Renewable Energy Source law project. It should be noted that during 17 months RES project evolved from version 2.0.1 (04.10.2012) through 4.2 (31.12.2013) to present form 6.3 (28.03.2014). It seems that transition from very optimistic assumptions like the possibility of introducing feed – in - tariff rates (as in many European countries), ensuring constant level of repurchase price for 15 years, to current model based on prosumer energetics significantly decreased profitability of investing in photovoltaics and may be uninteresting especially for people thinking about quick profits.
- Prosumer program introduced by National Fund for Environmental Protection and Water Management may be an interesting solution. It is a continuation of completed in the end of 2013 year solar collectors program and concerns photovoltaic systems up to 40 kW$_p$, wind turbines and heat pumps.
- Technologies are divided into two groups characterized by different levels of funding. Maximum allowed amount of the investment sum (so - called qualified costs), cannot exceed 100 000 zł and the maximum permissible realization period must be shorter than 18 months [17]. Program excludes the possibility of using used devices and PV modules.
- In order to improve the economic aspect it is preferred to maximize the use of produced electric energy that generates profits resulting from the current need to purchase electricity from the local operator. Energy storage problems seem to be also important because of impossibility in on - line consumption of produced electric energy.
- The Prosumer program also provides installation of energy storage in the form of batteries. They must meet certain requirements [16]. Limiting the size of the PV system increases self - energy consumption but can lead to unfavorable increase in cost per unit power, due to the cost of the inverters, which price does not change proportionally to the power.
- Basing on the analysis of seven variants of settlement of produced electric energy can be concluded that PV microinstallations can be attractive in case of widespread introduction of net - metering calculations. Value of produced electric energy can decrease electricity bills and provide extra profits when

consumption is lower than production. It could also justify the sense of electricity saving by individual consumer.

- One of the requirements for photovoltaic modules is their compatibility with one of the standard like PN-EN 61215 "Crystalline silicon photovoltaic modules (PV) for terrestrial applications-Structure qualification and type approval" or PN-EN 61646 "Thin-film terrestrial photovoltaic modules (PV)-Structure qualification and type approval".
- On the basis of economic simulation it can be concluded that the most preferred methods of settlement of produced electric energy are maximalization of own - consumption, leading to profitability of investment in case of financing using preferential credit (variant no 7), or resell to AC grid according to fixed rates (variant no 6). Low value of repurchase price in present RES project causes that payback period exceeds 17 years (option 1), where a significant part of electricity is used for own needs, and extends in case of partial use to 19 years (variant no 3).
- In many cases it is justified to use 2 - axis Sun tracking systems that leads to 42 % increase in electricity production and 24 % taking into account energy consumption for positioning processes. For installations with power up to 10 kW_p estimated increase in initial investment costs for 2 - axis tracking systems equals about 18 % [7].
- The best way to improve the economics of investing in photovoltaics is to return to feed – in - tariff rates in form presented 04.10.2012 (Variant no 2).

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