MONITORING OF PHOTOVOLTAIC INSTALLATION WITH ELECTRIC ENERGY STORAGE

Kruszelnicka W.[1], Mroziński A.[1], Polishchuk O.[2], Polishchuk A.[2]

[1] UTP University of Science and Technology, Poland

[2] Khmelnitsky National University, Ukraine

Introduction

The growth of the photovoltaic (PV) installations' market is being observed in Poland. The installations sector, in spite of the fact that the Law on renewable sources of energy does not guarantee the conditions for a dynamic growth, it is all the time in the growth phase [1, 2, 6]. According to the data from the Renewable Energy Institute and the Polish Photovoltaic Association, in the first quarter of 2016, the total power installed in the PV systems connected to the grid amounted to 119,2 MW [13, 14]. The world's market of PV installations increased in 2015 as compared to 2014 for 34%, and in Poland for up to 240%. Most of the specialists say, that such tendencies should maintain. Such a phenomenon is bailed out by a constant increase in efficiency of PV modules and the development of the energy storage systems [7, 9, 11].

A few years ago the development of the household photovoltaic installations in Europe was caused by gainful prices of energy's sale to the public power grids. Such a situation contributed to the fact, that the installations' owners did not use the generated electric power for their own use within the frames of the so-called „auto-consumption". Changes have been observed over recent years. In particular in Poland, due to the absence of advantageous systems of investors' support based on the feed-in tariffs, more and more often there come into being the dedicated PV installations for investors, who want to exploit power in whole or to a large degree for own needs [9, 11].

In the article there are presented annual studies on economic laboratory viability of an photovoltaic installation, in which the lithium-ion (Li-ion) storage facility of electric power.

Legal aspects of electric power storage in Poland

In RES and in the prosumer's segment, storage of the generated power becomes more and more important. Due to the fact of the development of the storage technologies and its increasing importance on the market, introduction of appropriate regulations to Polish law is needed [2, 3, 4].

In the context of energy storage, considering of the source of the renewable energy in the new definition of the hybrid installation is an important change. It is written: „such an assembly of installation may be also accompanied by the energy's storage generated by that assembly and then, electric power turned over is treated as energy from a renewable source''. The energy generated by RES and then stored at the energy storage and sold from it is the definition of energy from a renewable source. It is a very significant record, as this issue could be interpreted differently, not always expediently for the energy's generators [12].

In the provisions of this law it is also mentioned, that the electric power's seller is obliged to purchase the unconsumed electric power, which has been generated by a generator other than the prosumer, in micro installation with RES, including the one stored in the energy storage [12].

The statutory changes bring Poland closer to the European realities of energy storage. Producers of photovoltaic inverters in Europe start introducing dedicated solutions on the market, which shall make it possible to optimize auto-consumption of energy from household PV installations. Thanks to that, there is a possibility to storage the unconsumed energy surpluses and their consumption at the time when photovoltaic installations shall not provide appropriate supply [11].

Last years in Germany the rates of energy sale from household photovoltaic installations have been considerably decreased. As a result of that, it is much more profitable to use „green energy" for own use, saving on energy not purchased from an operator, the cost of which is almost 3 times higher than the rates of sale to the grid [12].

Construction of PV installation with an energy storage

The analysed photovoltaic installation is on the roof of the building 3.2 of the Faculty of Mechanical Engineering of UTP in Bydgoszcz (Fig. 1 - Fig. 2.). In the installation there have been used 20 monocrystalline modules of IBC Solar AG company, of the total power 5,6 kW. They have been fastened at the angle of 21^{o} to the horizon. Global insolation on a module amounts to about 1136,7 kWh/m^2 what results from the climate data for a given latitude. In the installation there have been used a three-phase inverter FRONIUS Symo Hybrid 5.0-3-S of the power of 5kW. The inverter of that type converts the direct current generated by the solar modules into alternating current. The alternating current supplies the public grid synchronously with the grid voltage. Moreover, the solar power may be stored also by the connected device Fronius Solar Battery for the purposes of its later consumption [8].

Fig. 1. Photovoltaic modules on the roof of the laboratory of UTP in Bydgoszcz [6, 8]

Fig. 2. Fronius Symo Hybrid 5.0-3-S S24 together with Fronius Solar Battery in the laboratory of UTP in Bydgoszcz

An inverter automatically monitors the public power grid. An inverter operates in such a manner, that the maximum possible power is collected from the solar modules. Depending on the point of work, that power is stored in an accumulator. When only a volume of power supplied by the solar modules stops being sufficient, then the household grid is supplied from the accumulators. A system like this is characterised by a maximum share of energy consumption for own needs and the maximum independence from the energy supplies. Fronius Solar Battery of the accumulator’s batteries capacity from 4,5 to 12kWhA depending on a customer’s requirements, is used to accumulate electric power. Fronius Solar Battery is the device comprising a lithium-ion-phosphate battery. This device somehow extends the device Fronius Symo Hybrid with the energy storage option. Thanks to that, it is possible to storage solar energy from solar modules for the purposes of its later use. The lithium-ion battery on the basis of ferrum phosphate ($LiFePO_4$) is used, what guarantees long life, short charging times and big depth of discharge. Exploitation of the energy storage system in connection with the inverter make Fronius is fully automatic [5, 6, 9].

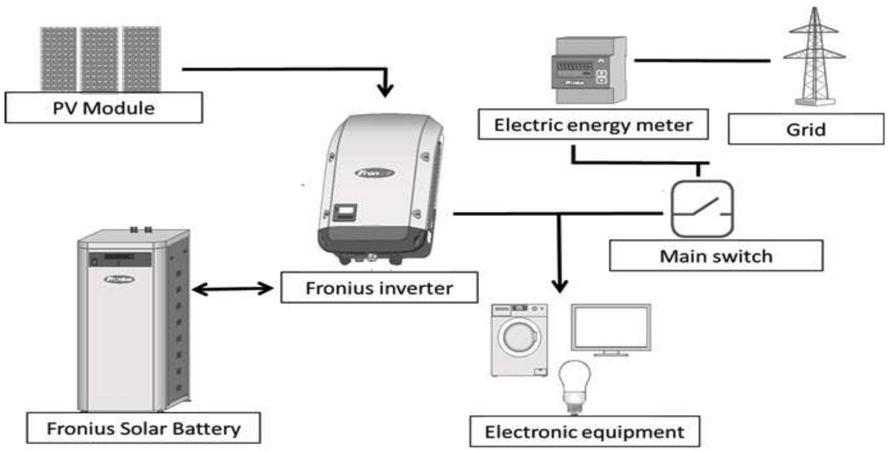

Fig. 3. Schematic diagram of the installation's operation with the energy storage [own study]

Moreover, during the studies there was used the dedicated application making it possible to monitor the photovoltaic installation via a website solarweb.com (following earlier logging in), thanks to what the preview of the installation's operating parameters is possible any time. In figure 3 there is presented a schematic diagram of operation of a photovoltaic system with the energy storage.

The installation is functioning in the following manner: generated electric power is supplied to the inverter, in the inverter there occurs the conversion of current from direct into alternating, then the household receivers are supplied; the unused electric power is accumulated in the battery, and in case when the energy is not generated due to the absence of sun, then the system uses the energy from the battery; if there occurs the surplus of electric power, then it is sent to the electric power grid; with the use of a software operation of the system may be monitored at any moment.

Methodology

Registration of data has been performed for the installations of photovoltaic modules located on the roof of the building 3.2. (WIM UTP in Bydgoszcz) with the use of Fronius Solar.web. The own consumption of the utility object was generated via energy receivers installed in the engineering laboratory of OZE WIM UTP in Bydgoszcz. The receivers consuming energy during the period of 24 hours was the lightning, computers and the research and development installations functioning in the laboratory (heat pumps, heaters, etc.).

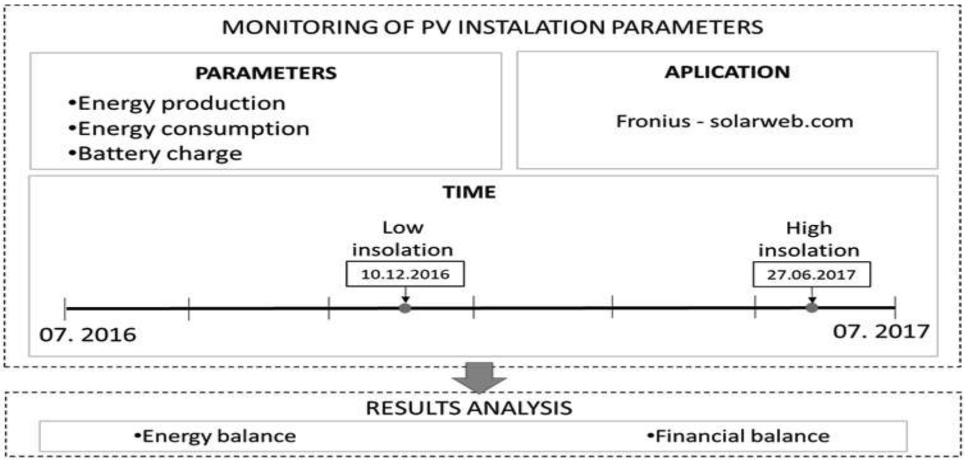

Fig. 4. Plan of monitoring studies concerning the PV installation [own study]

Surveys of the installation's operating parameters (that is consumption of power, state of accumulators' charge) with the power storage were conducted in July 2016 –July 2017. There were also examined the financial effects of the installation's operation: income on the sale of electric power, savings resulting from the consumption of the generated electric power and expenses incurred for the purchase of the electric power from the electric power grid's operator within the specified period of time. All the listed parameters were monitored and archived on an ongoing basis by the set Fronius Symo Hybrid 5.0-3-S S24 and Fronius Smart Meter. The plan of surveys is presented in figure 4.

In the first place there was analysed production, consumption of energy, the state of accumulators' charge within one 24 hours of low insolation – 10.12.2016 and within 24 hours of high insolation – 27.06.2017.

It has been assumed, that in case of a correctly selected size of a photovoltaic generator, a maximum big power independence of a selected utility object may be achieved. Taking into account the fact, that statistically one person per household consumes 2kWh of power per day and that the fact, that we posit the determined value of power supply from the grid, the optimization of own consumption and registry of the curve of a household's load may be realized.

Measurement results of the PV installation's operation with the energy storage

In the first place there was analysed the production, consumption of energy, the state of accumulators' charge within 24 hours of low insolation – 10.12.2016 (Fig. 5) and within 24 hours of high insolation – 27.06.2017 (Fig. 6).

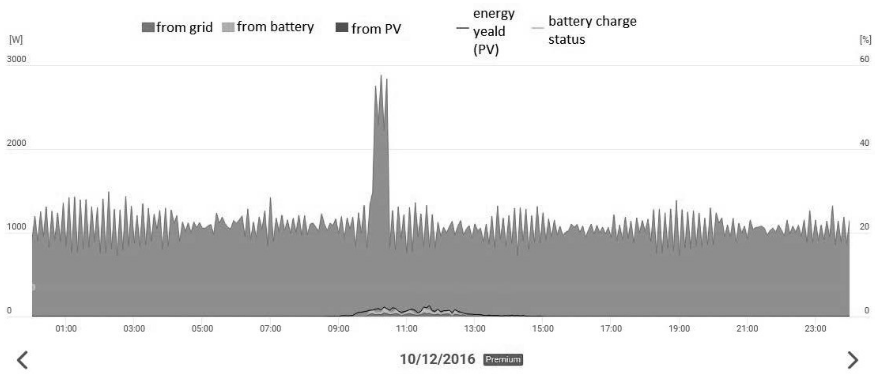

Fig. 5. Diagram of energy consumption on a day of low insolation – 10.12.2016 [10]

In case of low insolation, the energy in the first place is used for own needs, energy generation's surpluses as compared to the demand is used for charging accumulators (Fig. 6). On 10.12.2016 generation of energy in the installation amounted to 0,26 kWh, while consumption of energy 26,16 kWh. The energy generated and stored in the accumulators was very low as compared to the electric power demand, that is why a considerable part (almost 100 %) was drawn from the power grid.

In case of high insolation, the energy also in the first place is used for own needs, energy generation's surpluses as compared to the demand are used for accumulators' charging, and when they are fully charged then the surpluses are sold to the power grid (fig. 6). On 27.06.2017 generation of power in the installation amounted to 36,30 kWh, while consumption of power to 20,38 kWh. Energy's surplus of 23,44 kWh was sold to the grid, 4,09 kWh was used to charge the accumulators, and the remaining part was used for current receivers' feeding. Then the production and consumption of electric power in the months: July 2016– July 2017 was analysed (Fig. 7). The highest volume of the electric power from the photovoltaic modules was obtained in the examined period in May 2017 (750 kWh), the highest energy consumption was recorded in January 2017 (1382,64 kWh). In the months: July 2016 - September 2016 and May 2017 - July 2017, generation of electric power in the PV installation exceeded its consumption, therefore its surpluses could be sold to the electric power grid.

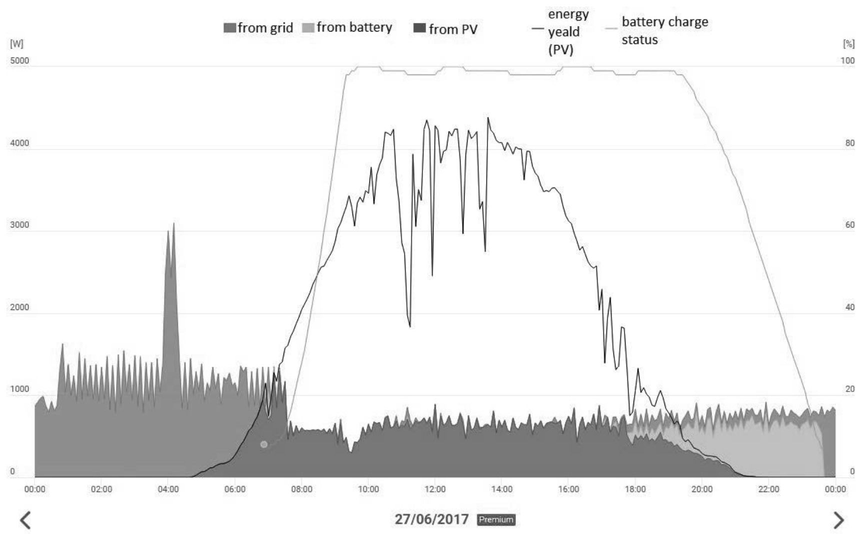

Fig. 6. Diagram of energy consumption on a day of high insolation – 27.06.2017 [10]

Energy generated by the installation was used directly by receivers located in the laboratory, sent to the battery or turned over to the electric power grid. In figure 8 it is presented how the electric energy has been managed in individual months.

The biggest volume of power generated (46 %) in the examined period July 2016 – July 2017 was turned over to the electric power grid. Energy turned over to batteries depending on a months, was within the range of from 18,13 kWh (January 2016) to 137,33 kWh (July 2017). Seasonality of occurring of periods of high and low productivity is noticed or generation of energy from photovoltaic installation, in summer months (May – September) high productivity, in winter months (October - April) low productivity cause by a shorth day and slight insolation.

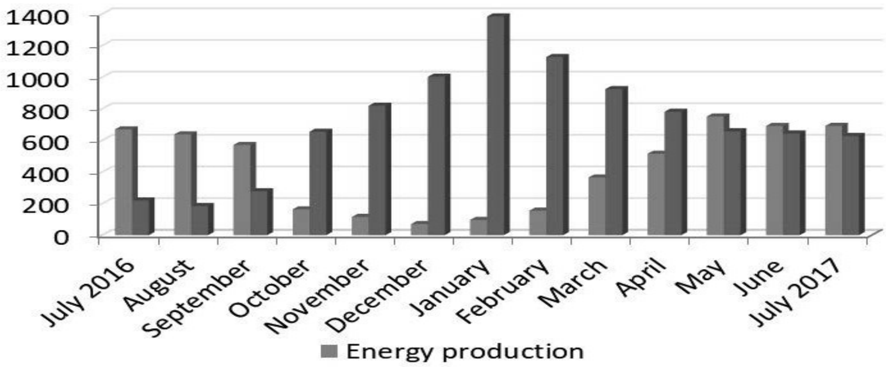

Fig. 7. Consumption and generation of energy from the examined installation with storage in the months: July 2016 – July 2017 [own studies]

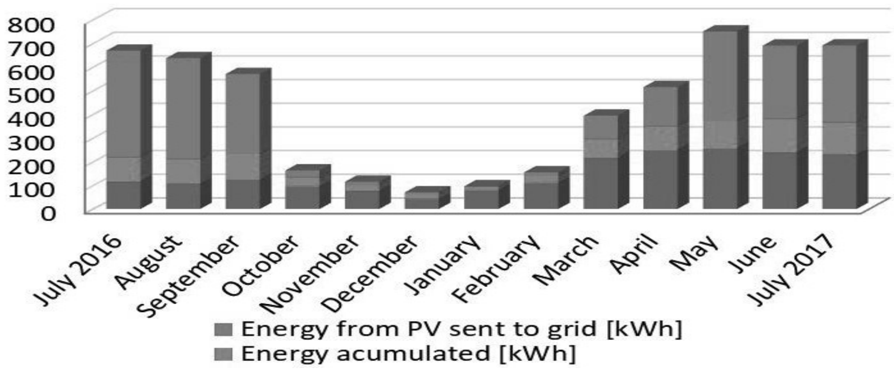

Fig. 8. Balance of power generation for the examined installation in the months: July 2016 – July 2017 [own studies]

The highest volume of energy consumed in the months: October 2016 - April 2017 originated from the electric power grid (Fig. 9). In the remaining months, higher volume of electric power came from the PV installation (was consumed directly by receivers and accumulated in a battery). Thanks to the use of batteries, a higher volume of energy from photovoltaic installation was used for receivers' feeding. For such a facility like the University, characteristic is the increased consumption of electric power in the winter period due to the taking place courses and the decreased demand for energy in the summer period caused by the summer break and the absence of courses. In such a case, the balance of power for the PV installations shall not be the most advantageous due to its low productivity in the winter period.

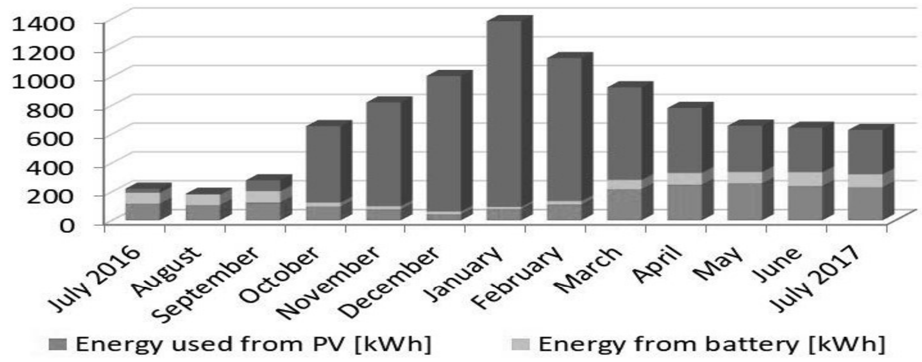

Fig. 9. Balance of energy consumption for the tested installation in the months: July 2016 – July 2017 [own study]

The financial effect for the installation's operation was checked. In the table 1 there is presented the financial balance of the installation's operation in the months April – August 2016. The total profit (income + savings) on the installation's operation in the studied period amounted to 3031,76 Pln, the income on the sale of the power 1355,43 Pln, savings 1676,33 Pln, and expenses for the purchase of power 4364 Pln. In the total balance of the electric power costs it is noticeable, that in the studied period of time, the amount paid for the electric power was 1332, 56 Pln while without operation of the installation the amount of 6040,65 Pln. would have been paid. Operation of the PV installation allowed to lower the costs incurred on the electric power for more than 80%.

The tested installation has been equipped with the electric power storage. Thanks to the operation of the battery, it was possible to increase the consumption of the electric power accumulated in it for own needs, that means coming from photovoltaic modules.

Table 1. Financial balance of operation of the tested photovoltaic installation in the months: July 2016 – July 2017 [own study]

THE FINACIAL BALANCE OF OPERATING PV INSTALLATION				
Month	Income [Pln]	Savings [Pln]	Expenditure on electricity from the grid [Pln]	**Balance [Pln]**
July 2016	233,57	123,29	19,17	337,69
August	221,63	115,08	4,43	332,28
Septemb er	176,54	126,77	53,51	249,80
October	16,37	66,14	358,80	-276,29
Novembe r	5,65	47,82	484,15	-430,68

Decembe r	1,39	23,43	627,70	-602,88
January	0,07	54,02	844,69	-790,60
February	8,27	86,40	645,62	-550,95
March	51,6	181,64	418,60	-185,36
April	86,58	213,44	293,71	6,31
May	203,75	216,67	210,31	210,11
June	170,94	215,48	202,17	184,25
July 2017	179,07	206,15	201,46	183,76
Anually	1355,43	1676,33	4364,32	-1332,56

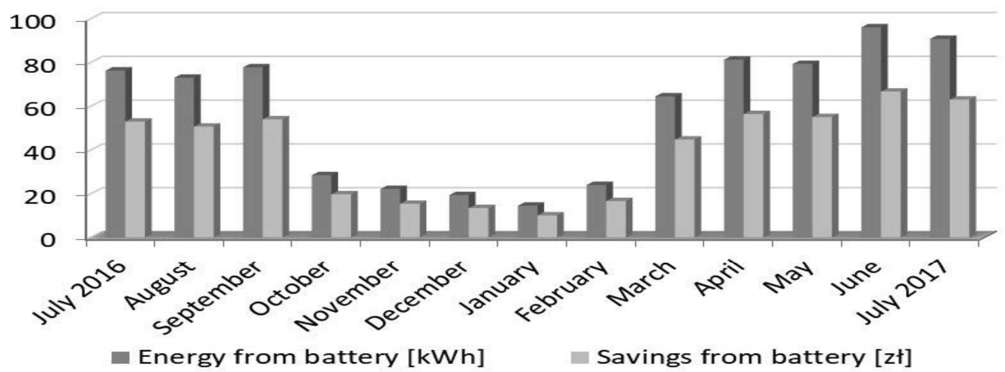

Fig. 10. Energy and economical benefits from cooperation of the energy storage with the photovoltaic panel in the months: July 2016 – July 2017 [own studies]

Figure 10 presents the energy and economical benefits resulting from a battery's operation. The highest volume of energy from a battery was taken in June 2017 (96,01 kWh) and for that month also the highest savings on the battery's operation (66,63 Pln) were recorded. In total in the studied range of time of the installation's operation, the energy collected from the battery amounted to 746,95 kWh, and savings resulting from the battery's operation amounted to 518,38 Pln.

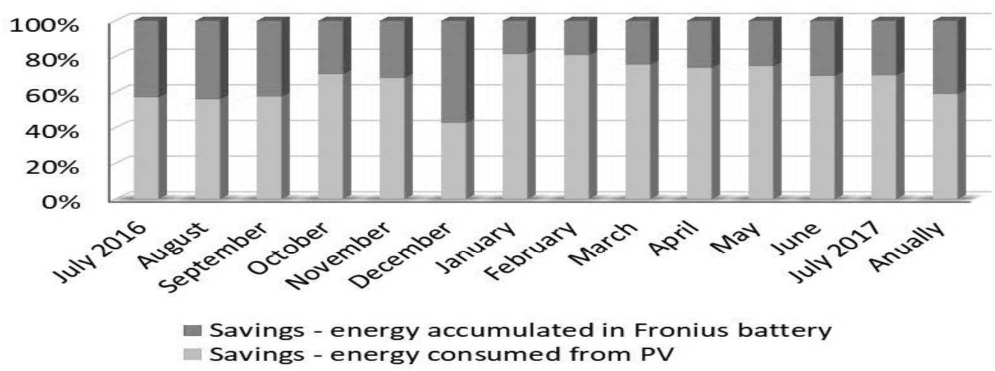

Fig. 11. Savings resulting from the operation of the tested installation detailing the savings earned thanks to energy storage [own study]

In the individual months, thanks to the battery's operation, the savings on the operation of the photovoltaic installation increased and amounted even up to 44% of all the savings - August 2017 (Fig. 11). In total for the tested 13 months of operation, the savings earned for the cooperation of the photovoltaic modules with a battery, constituted 31% of all the savings.

Conclusions

Performance of all the surveys made it possible to analyse the economical effectiveness of the PV installation with the energy storage in the Polish environmental conditions in the selected period of time (period from July 2016 to July 2017). At present the data make it possible to conclude, that the photovoltaic installations with the energy storage make it possible to generate savings and to lower the bills for electric power. The use of the energy storage in the PV installation enhanced the increase of the savings on the bills for 30 % [9].

At the time to the studies, there were attempts to gain full energetic independence of the laboratory of the Renewable Sources of Energy Engineering (www.LABIOZE.utp.edu.pl), which is supplied with the PV installation presented in the article.

All the existing at present electric energy's storage technologies have their advantages and disadvantages. The lithium-ion batteries chosen by the Authors to be analysed, are not ideally adjusted for too deep discharging what considerably limits their life. However, they are a beneficial solution in case of photovoltaic installations requiring storages connected to it frequent charging and discharging.

Available at present on the Polish market Li-ion batteries, make it possible to cover the demand of a statistic four-member family for about a few hours. Maybe this result is not impressive, but it may be increased by the increase of the number of batteries – however taking into account the economics of such a solution, it then becomes disputable.

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