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Research Article

ANALYSIS OF THE POSSIBILITY OF USING SOLAR ENERGY TO POWER SELECTED MEASURING DRIVES IN AGRICULTURE

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ABSTRACT
Mankind's misgivings caused by the depletion of fossil fuels have accelerated research on obtaining energy from unconventional sources. One such source is the Sun. The present article reviews the possibility of using solar energy, converted in batteries of photovoltaic cells into electricity, in agriculture and farming. It should also be emphasized that it is energy friendly to the environment, whose acquisition on agricultural land, which often lacks access to the power grid, is now legitimate and profitable. This study presents the results of computer simulations in tabular and graphical form, using the PVSYST program, for a pasture water pumping system for watering grazing cattle.

Keywords: photovoltaics, inverters, electric pumping systems, computer simulation.

INTRODUCTION

The use of solar energy in Poland, especially in the Lublin region, is characterized by a good sun exposure, is most reasonable. A number of publications point to the current profitability of autonomous systems, not connected to the power grid and removed from it by a few dozen meters (in urban areas) and even a few hundred meters (in rural areas).

The maximum use of energy from a PV generator is determined by the matching systems, through which the receivers are attached. Elements of the system, also known as inverters, are mainly to follow the maximum power point (MPP) in accordance with the control algorithm of the system.

The main arguments justifying the need to increase the share of energy from renewable sources, besides the fact that the stocks of conventional sources are running low, include the attempt to secure energy supply, and the progressive degradation of the environment caused by the increase of CO_2 in the atmosphere and threatening with serious and irreversible changes in the global climate. Reconciling the goals of energy security and environmental protection requires an increase in the share of renewable energy sources in the fuel-and-energy balance. It would contribute to improving the exploitation efficiency of raw materials as well as saving energy, upgrading the environment and reducing waste generation.

The quest for sustainable development bringing measurable energetic and ecological effects is becoming a priority in many countries around the world. It is achieved primarily through the rational use of energy from renewable sources, including solar energy. The technology of using solar energy is one of the most dynamically developing sectors in the field of renewable energy sources. The sun is the largest source of energy available to man, and this energy is completely free and inexhaustible. Direct and emissions-free conversion of solar into electrical energy is possible via photovoltaic cells. Because the current is generated in situ, energy loss due to transmission over long distances is avoided. Independence of energy supplies from the distributor, harmless impact on the environment and the possibility of a cheaper way of obtaining the resource make agriculture, housing and communication potentially the largest consumers of renewable energy.

There are many publications analyzing the structure and operation methods of photovoltaic converters powering drive systems. However, there is a lack of literature on the practical capabilities and cost-effectiveness of photovoltaics in agriculture, horticulture or animal husbandry.

To fill this gap, the object and purpose of this article is to analyze the possibilities of using PV generators to supply the selected devices in agriculture. Special attention is paid to the issue of selection of the parameters of such systems which determine their efficiency, performance, price and reliability. An important point of the article is an example of a photovoltaic system project for which simulations of action were carried out in the PVsyst computer program. Optimization and operational simulation was made of the pumping system used on a stock-raising farm. The simulation results and the relevance and feasibility of the use of the proposed system were also analyzed.

REVIEW OF APPLICATIONS OF PHOTOVOLTAICS IN AGRICULTURE AND FARMING

Photovoltaic panels can be a cost-effective solution for delivering electricity in remote locations such as farms and pastures. Photovoltaics can be much cheaper than installing power lines and transformers. The lower initial installation costs compared to other industries are also influenced by the fact that the systems used in agriculture in Poland usually does not require winter optimisation, which greatly overextends the system, and thus increases its costs. Photovoltaics is an ideal source of energy for agriculture, because the growing season coincides with the period of greatest availability of solar energy. Most applications of photovoltaics in agriculture take place in the months from April to October, when Poland experiences the greatest insolation. Additionally, because the generated current is typically used on the spot, one avoids energy loss due to its transmission over longer distances.

The water-pumping system for irrigation of farmland, vineyards and greenhouses

PV systems are often used to irrigate fields or plantations away from the power grid (Figure 1). There are many technologies of irrigation. Photovoltaic energy is still expensive, so special attention should be paid to the design of the system for the most efficient use of pumped water. Calculations must be made for the water demand for each crop. The planning should also include irrigation manner and crop size. A useful tool in the designing process is the DASTPVPS simulation program. It is a tool for computer simulations of photovoltaic pumping systems for irrigation. It is reasonable to use such systems in arid and semi-arid climates, and especially in locations distant from the power grid, where the water supply by means of e.g. tankers is in the long run impractical and cost-ineffective [Mermou 2006].

The water pumping system for providing drinking water to farm animals

In recent years, more and more developing countries opt out for photovoltaic pump systems.

Figure 1. A water pumping system for farmland irrigation [www.nrel.gov]

This technology has a great potential mainly due to the simplicity of implementation, many possibilities of use, reliability, lack of dependence on other energy sources, and beneficial effects on the environment. The advantage of these systems is also the possibility of storing water for later use during unfavourable weather conditions. Pump photovoltaic systems are used in two basic configurations: either submersible or surface pumps. Pumps can be powered both by DC and AC engines. In the simplest case a DC engine drive is connected directly to the PV generator. In the case of e.g. asynchronous engines an inverter is also needed that converts direct current generated by solar panels into alternating current required to power the engine. An example of a system for watering cattle is shown in Figure 2.

Aeration systems of fish ponds, water holes and lakes

The air in a pond, lake or water hole is important in the process of respiration of fish. In the summer, stagnant water very quickly runs out of oxygen, because it is consumed in the process of decomposition of dead plant parts. Additional ventilation of the tank improves the climate and living conditions of the fish populating ponds (Figure 3).

Table 1. Technical data

Solar module	The membrane pump
Max Power: 8 Wp	Air flow: 150 l / h
Voltage: 12 V	Supply voltage: 12 VDC
Current: 694 mA	Current: 350 mA
Short-circuit current: 822 mA	Cable length: 5 m
Open circuit voltage: 3.92 V	

A light aeration system normally consists of: a high-quality solar cell panel, a membrane pump and an air hose with a check valve.

THE CONCEPTUAL DESIGN OF THE WATER-PUMPING SYSTEM FOR WATERING CATTLE

The main source of power will be photovoltaic batteries, which convert solar radiation into DC electricity. A PV generator will power the drive unit of the water pump. The system does not provide backup power from battery or generator backup. Cooperation with the power grid is also ignored. Water will be pumped from a deep well into the tank on the surface, from where it can be distributed into special troughs or directly consumed by animals (Figure 4).

Figure 2. A photovoltaic generator powering a water pump in a pasture [www.nrel.gov]

Figure 3. The aeration system "Solar Air" [www.solarversand.de]

This solution is ideal for pastures away from buildings and the power grid. High cost of building the system is minimised in this case. It consists of a number of factors:

- The grazing season coincides with the period of greatest insolation and the highest temperatures, i.e. from May to September, when maximum power is obtained from photovoltaic cells and PV systems have the greatest efficiency. Hence, excessive overextension of the system is avoided because it is not necessary to optimise it for the winter, which significantly affects the cost of its operation.
- It is not necessary to use reserve sources of energy and additional system components, such as inverters or controllers.

Demand of cows for water and pasture grazing

Cost-effective pasture grazing of animals depends not only on the availability of good quality feed, but also the supply of animals in water. They should have permanent access to it. Often this is accomplished by bringing water to the troughs from the pen in cisterns, but this is cumbersome and costly. An alternative to such a solution may be a standalone water-pumping system powered by a PV generator (Figure 4).

All life processes in animals are held in an aqueous medium. Water is essential to such functions as the maintenance of body fluids or ion balance, transport of nutrients to and from the cell, digestibility, absorption and metabolism of nutrients, temperature control, or removal of harmful substances from the body. Water shortages cause stress, poor appetite, reduced feed efficiency, reduced milk production (87% of the milk is water) up to several tens of percent, and reduced weight gain. Cattle adults, adolescents and calves must therefore be provided with a permanent, unlimited access to clean water [Burblis 2011].

In our climate zone, out of the 365 days in a year, vegetation grows for 210–220 days, which is usually from late March to late October. During the remaining 140–150 days it is at rest (winter – latent life processes). During the growing season, one of the most effective and animal-friendly ways to use grassland is stock grazing. It usually takes about 160–170 days a year (from the first decade of May to mid-October), so it is shorter than the winter (or alcove) feeding, depending on the region, from 30 to 60 days [Burblis 2011].

The time of grazing animals (food intake) during the day should not be long. To complete the fed an animal needs about 8–10, and a maximum 12 hours. In addition to feed, one of the conditions for obtaining high performance cattle is providing them with adequate amounts of clean and healthy water. Cows in the daytime absorb water repeatedly (even up to 10 times). Water scarcity can often be much more dangerous for animals than its excess. Therefore, one should provide them with permanent access to water, because they always drink as much as they need.

The daily requirement of cattle to water is varied and depends on the following factors:

- age, weight and physiological state,

Figure 4. The water-pumping system in a pasture [www.nrel.gov]

- ambient temperature and humidity,
- diet (the type, quantity, humidity and composition of the feed),
- drinking system (quality, availability and water temperature),
- level of milk production (milk yield),
- usage of cattle.

Dairy cattle has a great demand for water, which is reflected in the fact that water represents 87% of bovine milk. It is understood that the production of 1 litre of milk a cow consumes 3 to 5 liters of water. With a yield of 25 gallons of milk per day, a cow removes with it approximately 22 liters of water.

High-yield dairy cows during peak lactation require a daily dose of up to 25 kg of dry feed. The effectiveness of such a cow is on average more than 20 liters of milk per day. For each kilogram of dry weight a cow should receive between 4 and 6 litres of water. And assuming that the production of a litre of milk requires 3–5 litres of water, the daily demand of cows for water can be calculated. And so a high-yielder cow producing more than 20 liters of milk and eating 25 kg of feed needs up to 120 liters of water per day.

The average demand for water in cattle [Burblis 2011]:

- calves 4–8 weeks – 4–7 l/day
- heifers 8–20 weeks – 7–18 l/day
- heifers 20–26 weeks – 18–23 l/day
- pregnant cows – 30–60 l/day
- cows in lactation – 50–120 l/day
- dry cows – 50 l/day

Design assumptions

The project provides for a system for pumping water from a deep well into a reservoir in the pasture, supplying water to a small herd of cows in the period from May to October. A sample flock has 20 adult animals and 5 calves. The dose varies depending on weather conditions, animal age and body weight. Average daily requirement per cow while grazing in the pasture is assumed to be 60 liters of water. To assure consumption of the daily intake of water for the cattle, the construction of a reservoir is expected with a capacity of 2000 litres.

Computer simulation and selection of system components in the Pvsyst program

Determination of the spatial orientation of the plane of the collector

A collector was chosen with a fixed 28° inclination and 0° azimuth (facing south). This is the optimisation of the inclination angle of the plane of the modules for the production of energy in the summer.

Results and conclusions from the simulation of the designed system in the Pvsyst program

The end result of the simulation are numerous charts, diagrams and calculations which include a number of data, both meteorological and for individual elements of the system. This information illustrates how the system works, its effectiveness, suitability for a particular purpose and conditions and cost effectiveness.

After the initial calculations and computer simulations, the Solarjack SDS-D-128 pump was chosen, which is intended to be powered by DC directly from the PV generator. The appearance and characteristics of the pump are shown in Figure 5.

Selection of photovoltaic modules

In order to obtain relevant parameters (power, voltage, current) cells are combined with each other. Due to the parallel connection of the cells, the same voltage gives us current gradation of modules. On the other hand, by the series connection of the cells voltage variation is obtained. In this way, by performing a variety of configurations, we can get a PV generator of any power, current and voltage [Jastrzębska 2013].

To supply the planned system, polycrystalline silicon modules from Kyocera KC40 were chosen. The proposed photovoltaic generator consists of four modules, each with the power of 40 Wp. The modules are joined two by two in series and in parallel. The data sheet and characteristics of a single module are shown in Figures 6 and 7.

After the selection of pumps and modules, the final step is the selection of the parameters of the control device (controller). Based on the results of many simulations, a system with an MPPT converter was designed, whose block diagram is shown in Figure 8.

By using technology allowing to track the maximum power point (MPPT), maximum performance was provided at all times and in all weather conditions from the panel of photovoltaic modules or an individual photovoltaic module. The controller can operate with any input voltage (U_{oc}) of the photovoltaic modules. This property of the controller makes sure that any photovoltaic modules [Jastrzębska 2013] can be used in the MPPT systems for nominal voltages of 12 V/24 V.

For a pumping system of this kind simulations of its performance in different weather conditions were carried out in the PVSYST software. Selected results of the simulations are shown in Figures 9, 10 and 11.

The daily water requirements for the designed system were adopted at 1300 liters in the summer months, which gives approximately 40 m^3 of water per month. The bar graph shows the amount of water pumped through the system (burgundy), the amount of water supplied to the user (green) and the amount of water missing (purple). The designed system meets the design assumptions.

Current water demand does not always coincide with the period of availability. Therefore, each photovoltaic water-pumping system should have some type of energy storage, which will ensure a steady supply of water. The project adopted for this purpose a water tank with a capacity greater than the daily requirement. Another solution may be a battery pack that stores excess energy on sunny days and can be used on cloudy

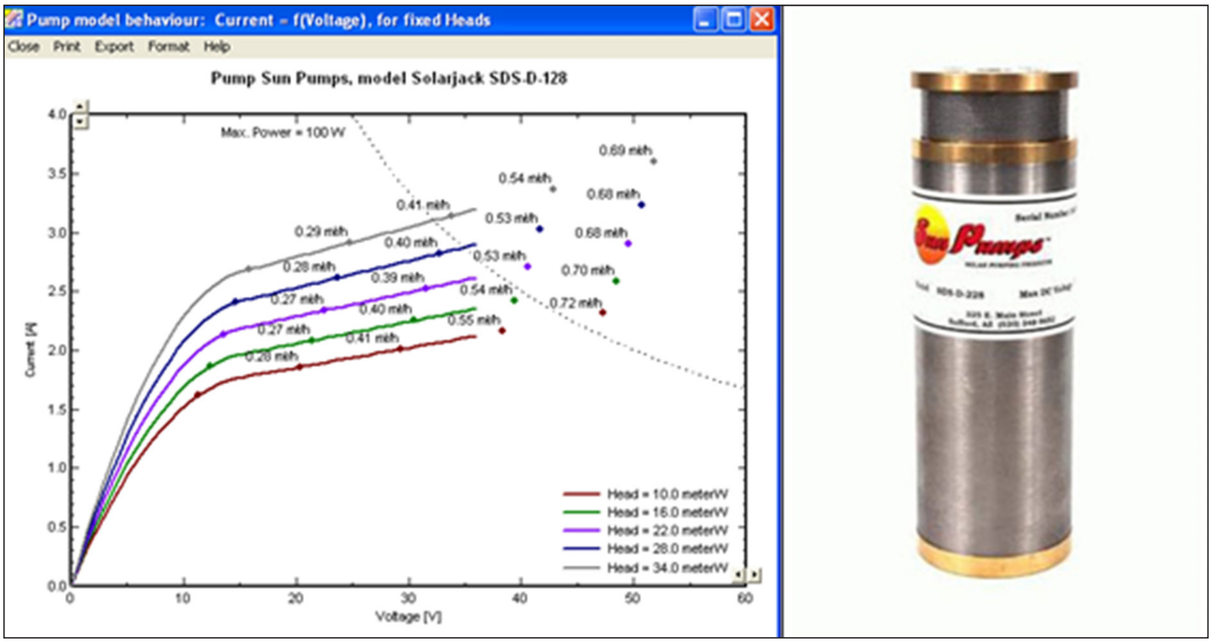

Figure 5. The characteristics and design of the Solarjack SDS-D-128 pump

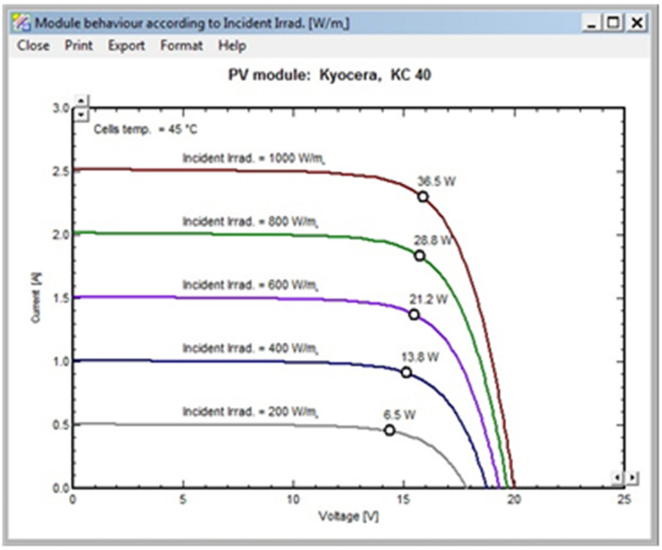

Figure 6. Current and voltage characteristics of the Kyocera KC40 module

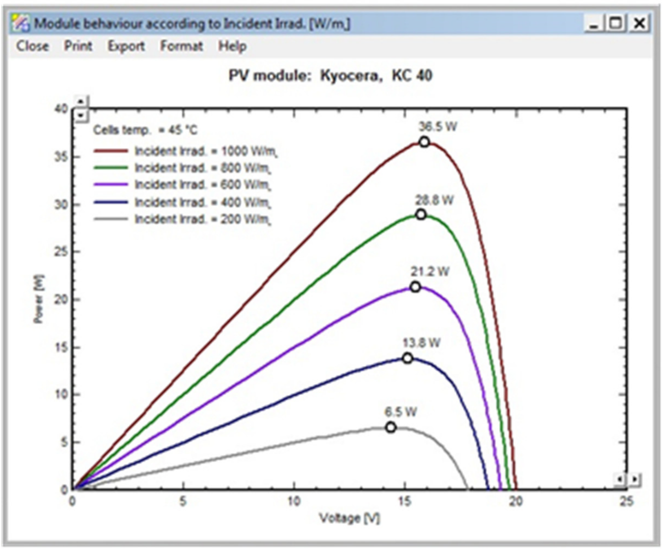

Figure 7. Power characteristics of the Kyocera KC40 module

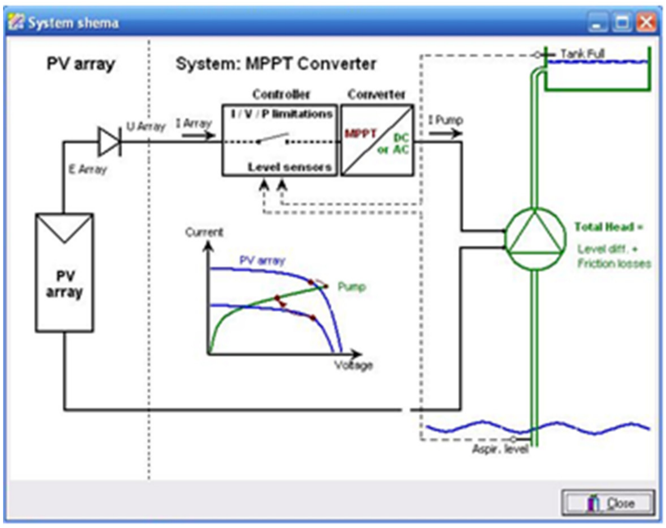

Figure 8. Block diagram of the designed system

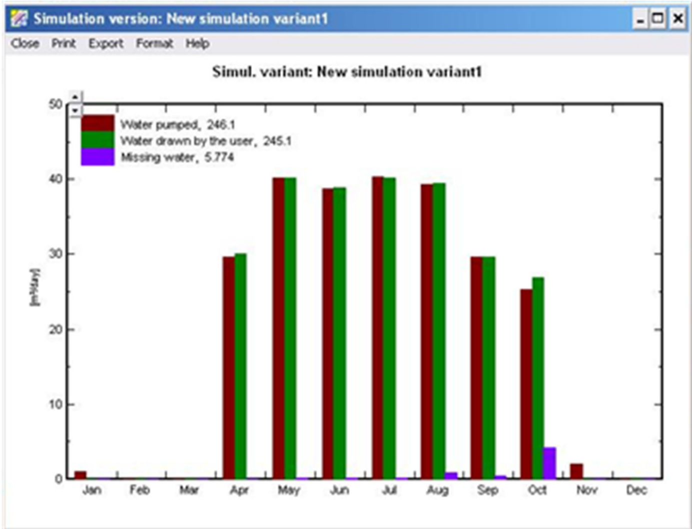

Figure 9. Monthly amount of water pumped, supplied to the user and missing.

Simulation variant : New simulation variant1

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New simulation variant1

Balances and main results

	GlobEff	EArrMPP	E PmpOp	ETkFull	H Pump	WPumped	W Used	W Miss
	kWh/m²	kWh	kWh	kWh	meterW	m³/day	m³/day	m³/day
January	28.3	3.95	0.153	2.28	13.01	0.032	0.000	0.000
February	48.5	6.83	0.000	4.93	0.00	0.000	0.000	0.000
March	86.7	12.02	0.000	9.71	0.00	0.000	0.000	0.000
April	118.0	16.01	4.916	8.76	13.01	0.989	1.000	0.000
May	158.9	20.92	6.407	11.77	13.02	1.296	1.297	0.003
June	146.2	18.96	6.152	9.94	13.02	1.290	1.296	0.004
July	158.7	20.41	6.492	11.12	13.02	1.301	1.295	0.005
August	145.9	18.75	6.524	9.51	13.02	1.270	1.272	0.028
September	95.4	12.64	4.809	5.60	13.01	0.989	0.987	0.013
October	71.8	9.75	4.090	3.33	13.01	0.814	0.866	0.134
November	32.0	4.38	0.312	2.39	13.01	0.067	0.000	0.000
December	19.8	2.73	0.000	1.65	0.00	0.000	0.000	0.000
Year	1110.3	147.36	39.855	80.99	13.01	0.674	0.672	0.016

Figure 10. Simulation results

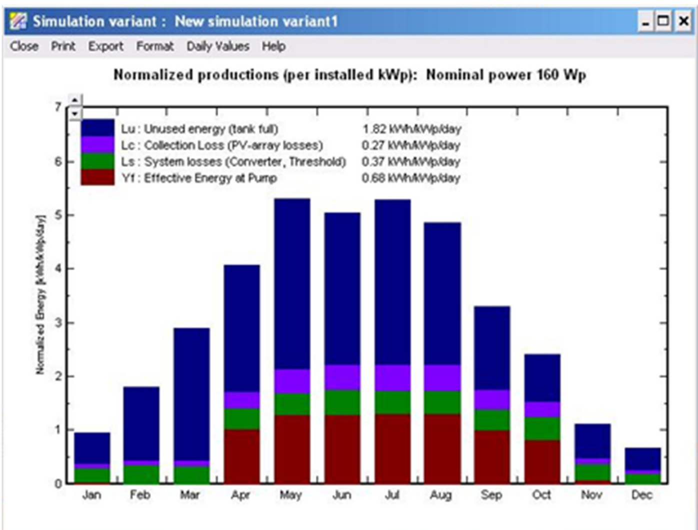

Figure 11. The energy distribution system

days. However, the use of batteries increases the cost of the entire system.

The designed system is fully autonomous. The main power source is a PV generator. We skipped the opportunity to work with the network, a back-up generator or a set of batteries. Water is pumped from a deep well into the reservoir on the surface, where it can be distributed into special troughs or directly ingested by animals.

This solution is ideal for pastures away from buildings and the power grid. The system costs in this case are partially minimised by the summer optimisation of the system and the lack of need for a backup power source. Comparing the costs of bringing power lines to remote pastures with the costs of exploiting solar energy, a photovoltaic plant for pumping water becomes a viable source of electricity. However, there is no single specific rule as regards the comparison of the costs of electricity supply with the installation of the solar system. It depends on the project location and the proximity of power lines. At a time when the cost of power supply from the power grid becomes an important part of the total cost of the project, the more obvious and cost-effective alternative turns out to be solar energy [McDilda 2007].

CONCLUSIONS

Analysing the results of the simulations it can be concluded that the designed system fully meets the design assumptions. Virtually the entire water demand is covered by solar energy. Slight water shortages in the autumn months can be considered negligible. This may be due to a lesser intensity of solar radiation in the given climatic conditions. This condition can be improved by using cells with more power, but the system would then be much more oversized in the summer months and would raise the total cost of installation.

The amount of energy generated, despite the losses associated with the flow, system losses or differences resulting from different levels of insolation, is more than enough to cover the daily requirements of the receiver. A large surplus of recovered energy can be used for other purposes, for example area lighting or powering a small medical facility.

The simulation results of the operation of the system illustrate and confirm the suitability of the use of simulation programs in the design of photovoltaic systems. A number of charts and tables from the simulation show the problems that arise at each stage of the project and allow to optimise the system, which in turn translates into efficiency and reduces the cost of the system. The cost of the designed PV generator is estimated at around 180 euros, which is less than the cost of connection to the recipient's existing power grid. The costs of other components of the system are the same for all the ways of obtaining power, and for this system amount to about 100 euros.

Solar water pumping systems are ideal in locations distant from the power grid, in developing countries and rural areas. This technology has a great potential mainly due to the simplicity of implementation, many possibilities of use, reliability, lack of dependence on other energy sources, and beneficial effects on the environment. An advantage of these systems is also the possibility of storing water for use during unfavourable weather conditions. Solar pumping plants require virtually no maintenance or depreciation repair. They are also characterised by ease of use, reliability and long service life.

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