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PHOTOVOLTAIC IRRIGATION SYSTEMS

FOTONAPONSKI SISTEM U NAVODNJAVANJU

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ABSTRACT

Photovoltaic conversion of solar energy into electrical energy has been used worldwide for several decades. In the field of agriculture, there is a need for electricity in remote areas which are often far from the electrical network and where the construction of such network would not prove cost-effective. Using photovoltaic systems this problem could be overcome. Photovoltaic energy is widely applicable in agriculture, especially in irrigation systems. This paper presents photovoltaic systems which are applicable in the irrigation systems. The descriptions of the autonomous DC photovoltaic system, the photovoltaic system with storage of electrical energy and the photovoltaic systems connected to the electricity distribution network are presented. The experimental results obtained for the photovoltaic system connected to the electricity distribution network are also included. All these types of photovoltaic systems can provide the necessary power for the operation of plant irrigation system in all weather conditions, as confirmed by the conducted measurements.

***Key words**: renewable sources, photovoltaic systems, irrigation.*

REZIME

Fotonaponsko pretvaranje energije sunčevog zračenja u električnu energiju se u svetu primenjuje nekoliko decenija. U poljoprivrednoj delatnosti postoji potreba za električnom energijom na mestima koja su često udaljena od električne mreže, a izgradnja iste je neekonomična. Korišćenjem fotonaponskih sistema manjih snaga stvorena je mogućnost proizvodnje električne energije i na takvim mestima. Jedna od mogućih primena fotonaponskog sistema je u navodnjavanju. Rad daje moguća rešenja fotonaponskih sistema, a koji su primenljivi u sistemu za navodnjavanje. Razmotreni su direktni jednosmerni fotonaponski sistemi, fotonaponski sistem sa skladištenjem električne energije i fotonaponski sistemi spojeni na distributivnu električnu mrežu. Prikazani su i eksperimentalni rezultati za fotonaponski sistem sa mogućnošću spajanja na distributivnu mrežu. Sve pomenute vrste fotonaponskih sistema obezbeđuju mogućnost navodnjavanja biljaka pri svim uslovima, što potvrđuju i izvršena merenja.

***Ključne reči:** obnovljivi izvori, fotonaponski sistem, navodnjavanje.*

INTRODUCTION

Solar energy, as one of renewable energy sources, is widely used for generating thermal energy, electricity and light. Conversion of solar energy into thermal is one of the first types of application of this sort of energy. Not so long ago, the conversion of solar radiation into electrical energy has started by means of photovoltaic cells. The latest type of exploitation of sunlight is not its conversion into a different type of energy, but its application in indoors illumination. All three types of conversion are, i.e., may be used in agriculture as well (*Radojčin, M., et al., 2007*).

SUBJECT

Electrical energy is essential for everyday operations of human society. Power stations and transmission systems supply electricity to end-users. The problem arises when a demand for electricity cannot be met due to a large distance between the consumer and the public grid. Providing electricity to the consumer by way of developing additional transmission systems could seem as an option, but its cost-effectiveness in comparison with other alternatives should certainly be taken into account. Cost-effectiveness primarily depends on the distance between the consumer and the grid, as well as on the expected consumption (*Čorba Z, 2009*).

In terms of agriculture and its subtypes, a demand for electricity in remote places, where development of a grid would not be economical, is often an issue. This is frequently a case in irrigation as well. Nowadays, diesel pumps are widely used in irrigation, but as the price of fuel goes up the total costs in the exploitation period follow as well. In contrast, new technology developments reduce the cost of initial investment in photovoltaic systems, and the force which powers the installation, i.e., solar energy, is entirely free-of-charge during the exploitation period. The figure below shows an annual solar energy flow.

Fig.1. Photovoltaic irrigation system

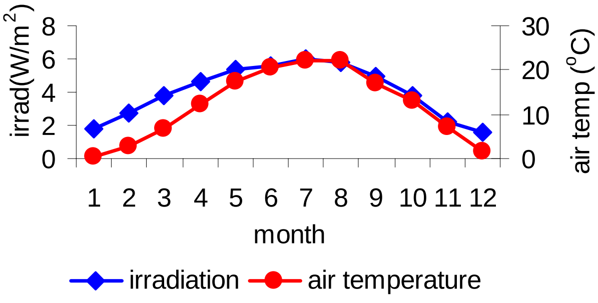

Fig. 2. Annual solar energy flow

Annual fluctuations in the air temperature correspond to fluctuations in the amount of solar radiation. As the mean daily temperature and solar radiation grow, crops demand more and more water. The direct proportion of the amount of solar radiation and the demand for water facilitates development of photovoltaic systems with minimum investments. This is particularly true in the summertime when a more flexible irrigation management is allowed for.

RESULTS AND DISCUSSION

A type of photovoltaic system applied in irrigation primarily depends on the season, crops which are irrigated and geographic location of the irrigated area.

Photovoltaic systems which can be used in irrigation are:

- Direct DC photovoltaic system
- PV system with storage
- Grid-connected PV systems

Direct DC photovoltaic system

The simplest and the cheapest photovoltaic system is a direct PV which consists of a PV panel, a control unit, and an irrigation pump (Fig. 3). This system does not contain a battery which makes it applicable only when there is enough solar energy. Due to the fact that its usage is limited by weather and daylight, this system should entail water accumulation. One of the options is to place a water tank at an appropriate height. This type of irrigation, with the water tank placed at an appropriate height, is typically known as a low pressure system – applied in drip irrigation. As the system does not contain a battery, it is vital that it is able to transfer all the power generated by the photovoltaic panel to the water extraction pump. For this reason, the control unit should be able to fully utilize the power of photovoltaic panel.

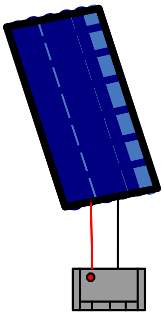

Fig. 3. Direct DC photovoltaic system

PV system with energy storage

The Fig. 4 shows the components of a PV system with energy storage. With minimum investments, such system can be used in the summertime regardless of the type of crops, i.e., their demand for water, or whether they are exposed or in greenhouses. The system consists of a PV panel which converts sunlight into DC output, i.e., electricity. Nowadays, there are panels on the market with a wide scope of output power from just a few W to a few hundreds. If needed, PV panels may be connected in series, parallel or both. Required capacity of PV panel depends on the power of irrigation pump which, consequently, depends on the size of irrigated area, i.e., a demand for water.

Electrical energy is stored in a battery designed for PV systems and its purpose is to compensate for insufficient generation of energy on cloudy days or at night. Batteries with minimum capacity can be used for drip irrigation given that, if such system is applied, crops would be watered even by day, regardless of the high temperature of air. Batteries with high capacity are required if irrigation is carried out at night, i.e., if a spray irrigation system is applied.

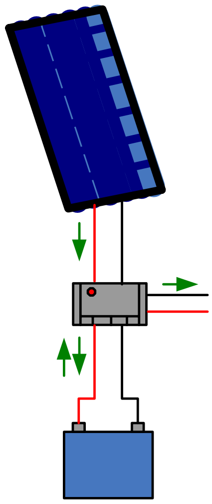

Fig. 4. PV system with storage

In order to avoid a full discharge, which reduces the battery life, or an overcharge which might destroy the battery, it is important to use a charge regulator. These devices connect DC consumers to PV systems while providing a full control of battery status. All charge regulators by well-known manufacturers contain a micro-control unit which further increases beneficial contribution of the system. Cheaper and less smart regulators are not able to transmit the full output power of PV panel to the battery. More expensive and smarter regulators allow for monitoring of maximum power of PV panel, which means that they transmit full power of PV panel to the battery, i.e., the consumer.

If a PV system is intended for AC consumers, it should contain an inverter, an energy-electronic device which converts DC voltage into AC. Each component of the PV system reduces the total efficiency of the system, which is why it is important to keep the number of components as low as possible. In terms of irrigation, such approach is viable as inverters are not compulsory. There are special submersible and surface pumps powered by DC motors developed for PV systems.

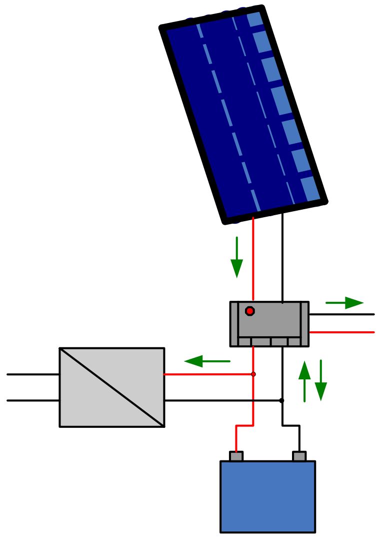

Fig. 5. PV system with storage for AC consumers

This type of PV system can be used for irrigation in greenhouses in early spring, late autumn or winter. Depending on the equipment of the greenhouse, electricity generated by the PV system may be supplied to other consumers as well. However, the design of PV systems used for greenhouses is quite complex. Given that greenhouses are typically used in months when solar radiation is lower by default, the required power of PV panels and the battery capacity increase, subsequently leading to higher investments in comparison to field irrigation in summer time.

Grid-connected PV system

Glass and plastic greenhouses are often located near residential areas where a low voltage public grid is already developed. In such cases a PV System, shown in the figure below, can supply the consumers, when there is enough sunlight, and take required electrical energy from the grid when solar radiation is not sufficient. Such system also allows for continuous supply in case of blackouts and guarantees permanent powering of a circulator pump used for greenhouse heating.

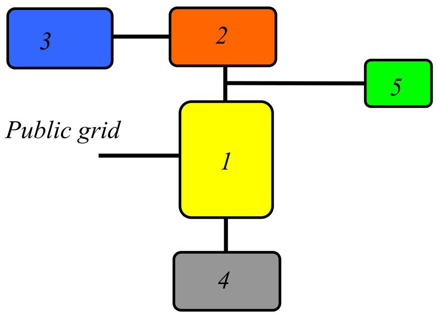

Fig. 6. Block scheme of PV Grid-connected PV system

A PV system is comprised of a multi-functional central unit (1) performing as an inverter and battery charger, and also supervising and managing the entire system. This unit connects the PV system to the public grid. If necessary, an engine-generator can be added as well. A local AC grid, of 230V voltage and 50Hz frequency, is formed at the output connection points of the central unit. Consumers are connected to this grid (5). Furthermore, PV inverters (2) may be connected as well, converting DC voltage, generated from PV panels (3), to AC voltage. In addition, an appropriate inverter with wind generator may be placed where there is sufficient wind energy potential. As an option even a mini hydro-power plant can be connected to the grid. Apart from an AC local grid, a DC grid with a battery (4) may be formed as well to supply certain consumers. Depending on the type of consumers, a system may contain only an AC grid, only a DC grid or both (*Corba, et al.,2009*).

These systems may have an exit power of a few kW or more and, apart from irrigation systems, easily provide power for other consumers as well. In addition, if more electricity is generated, the system allows for energy to be returned to the public grid, i.e., to be sold to the local supplier.

Practical experience

In order to be as efficient as possible in harnessing available solar radiation by way of PV systems with storage, especially in months when sunlight is scarce, it may be a good idea to use all available enhancements:

- high-efficiency PV panels
- devices which maximize the efficiency of PV panels
- solar trackers

The Fig. 7 shows the measured PV panel output power on a sunny October day. A stationary PV panel is positioned at an angle of 45° and alternately connected to a standard charge regulator and an MPP regulator (*Krga, et al., 2009*). When the latter was applied, the amount of generated electrical energy increased by 10%. When a two-axis solar tracker (Fig. 8) was added, an increase amounted to 30%. As the amount of generated electrical energy went up, the water available for irrigation followed proportionally (*Krost and Swewers, 2009*).

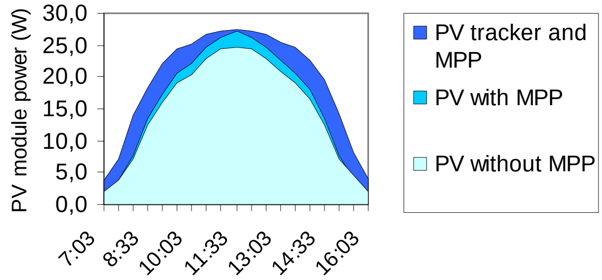

Fig. 7. Measured PV panel output power

Fig. 8. Experimental two-axis solar tracker

A Grid-connected PV system is installed at the Faculty of Technical Sciences in the Laboratory for Renewable Energy Sources of the Department of Power Electronics. The installed PV panels have the power of 1 kWp, invertors 1.1 kW, central unit 3 kW and the battery 9.6 kW. Fig. 9 shows the fluctuations in solar radiation over the period 2nd-19th February 2010, and the Fig. 10 presents the rise in the amount of generated electrical energy on a daily basis. The total amount of electrical energy generated in the above stated period of time equalled 14 kWh, and the total solar radiation 24.78 kWh/m^2, whereas average daily solar radiation amounted to 1.65 kWh/m^2, which was important not only for supplying the adequate amount of water for irrigation but also for the estimation of an adequate size of PV system.

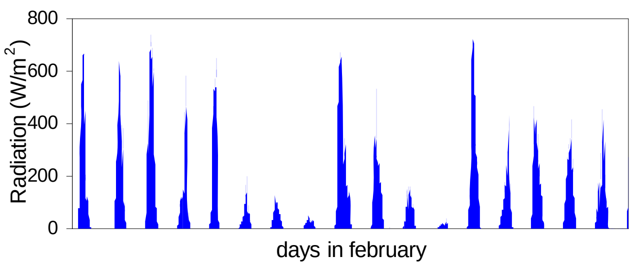

Fig. 9. Fluctuations in solar radiation

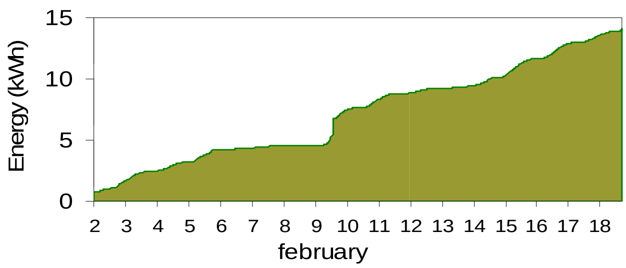

Fig. 10. Generated electrical energy

The Fig. 9 shows the fluctuations in solar radiation on two different February days. February 16th featured characteristics typical of that month – cloudy with short sunny intervals. 1.53 kWh of electrical energy was generated on that day, while average solar radiation amounted to 2.05 kWh/m^2. On February 13th, the snow covered PV panels due to which the generation of electrical energy was insignificant. In terms of PV systems with storage which consume approximately the same amount of energy on daily bases, a battery of larger capacity would be required in such situation. In winter, in greenhouses there is no need for everyday irrigation especially on cloudy days. This fact may be used to align demand for irrigation and generation of electrical energy in order to minimize the power of PV components and, subsequently, minimize investments. For example, a surface centrifugal pump of a typical power/height shown in the figure below (Fig. 11) would, over the period, supply between 7 and 24 m^3 of water/day depending on the height. The same figure shows an amount of water which can be extracted for the given time period. Having in mind that after November, December and January, February is the month when solar radiation is at its lowest, a more significant amount of water may be expected to be available in the rest of the year.

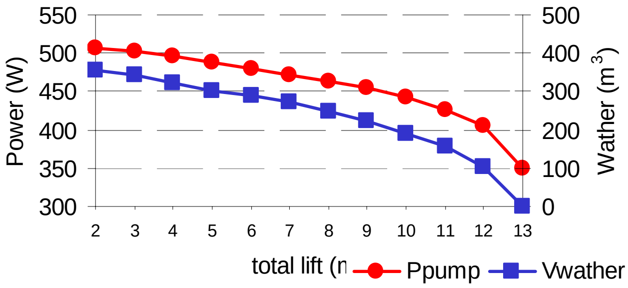

Fig. 11. Characteristics of a centrifugal pump

CONCLUSION

The abovementioned types of photovoltaic systems enable crop irrigation under any conditions. Technically less complex systems are applied throughout the months when solar energy is sufficient. If irrigation is demanded in the period when solar energy is scarce, a more complex and thus more expensive PV systems are required.

Initial investments in PV systems for the purpose of irrigation may be higher than investment in diesel pumps, but over the years, owing to lower maintenance costs and the fact that solar energy is free-of-charge, the total cost of PV systems, in fact, turns out to be lower. As the years go by the cost-effectiveness of PV systems becomes even more obvious.

The presented experiment showed that devices such as MPP regulators and solar trackers significantly contribute to efficiency of a PV system. These make the PV system more cost-effective as they allow for a reduction in the power of PV panels the price of which is one of the major issues. Greater fluctuations of solar radiation throughout the day, especially in winter, lead to daily fluctuations in the amount of generated electrical energy. However, if both systems are managed in a synchronized way, this may not require for an increase in the total power of the system.

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