Srete Nikolovski, PhD

Faculty of Electrical Engineering Osijek K. Trpimira 2B, Osijek Phone: +385 31 224 600: Fax: +385 31 224 605 srete.nikolovski@etfos.hr

Goran Knežević, PhD

Faculty of Electrical Engineering Osijek K. Trpimira 2B, Osijek Phone: +385 31 224 661: Fax: +385 31 224 605 goran.knezevic@etfos.hr

Mario Kresonja, M.Eng.

Solar Projects Ltd. Stjepana Radića 29, Osijek Phone/Fax: +385(0)31 327 018 mario.kresonja@solarniprojekti.hr

Jurica Gorup, M.Eng.

Solar Projects Ltd. Stjepana Radića 29, Osijek Phone/Fax: +385(0)31 327 018 jurica.gorup@solarniprojekti.hr

PHOTOVOLTAIC POWER PLANTS IN SLAVONIA AND BARANJA: EXPERIENCES IN THE DESIGN AND OPERATION

ISKUSTVA U IZGRADNJI I EKSPLOATACIJI FOTONAPONSKIH ELEKTRANA U SLAVONIJI I BARANJI

ABSTRACT

The paper describes the basics of converting solar energy into electricity. Furthermore, the application possibilities of solar energy conversion according to insolation maps of eastern Croatia are analyzed. The positive and some negative experiences in the construction of photovoltaic (PV) power plants in Slavonia and Baranja are notified. Cooperation of the Faculty of Electrical Engineering in Osijek and Solar Projects Ltd, one of the leading companies in Croatia in the field of solar power plants, began with the first non-integrated PV power plant on the ground SEG1, rated power of 30 kW. This was followed by the rapid development of the company Solar Projects Ltd. in the field of design, construction and maintenance of PV power plants. Until today, the company has performed more than 70 projects of the solar power plants with various rated power, from smaller 10 kW, 30 kW up to high rated power such as 120 kW, 180 kW and 300 kW PV power plants. In this paper, the total electricity produced from these PV power plants so far, as well as significant savings in carbon emission due to electricity produced using solar energy are shown. Furthermore, application of modern ICT and web technologies for distance measuring, monitoring and diagnostics of PV power plants, and technical specifications and diagrams of power production for a typical PV power plant are presented.

Key words: Solar energy, Photovoltaic power plants, Electrical energy, Carbon emission, ICT technology, Sunny Web portal

SAŽETAK

U radu će biti prikazane osnove pretvorbe sunčane energije u električnu energiju. Opravdnost primjene energije sunca kroz prikaz insolacijskih karata za područje istočne Hrvatske će biti u radu naznačene kao i iskustva u izgradnji fotonaponskih elektrana u Slavoniji i Baranji. Suradnja Elektrotehničkog fakulteta u Osijeku i jedne od vodećih tvrtki u Hrvatskoj na području sunčanih elektrana započela je s prvom FN elektranom snage 30 kW na tlu SEG 1. Nakon toga je uslijedio nagli razvoj tvrtke Solarni projekti d.o.o u području projektiranja, izgradnje i održavanja fotonaponskih elektrana. Sada tvrtka ima izvedenih preko 70 sunčanih elektrana različitih snaga od manjih 10 kW, 30,kW sve do većih snaga 120 kW, 180 kW i 300 kW. U radu će biti prikazana ukupno proizvedene električna energija iz tih elektrana do sada,kao i u ušteda u emisiji CO2 u tonama koja je značajna, temeljem proizvedene električne energije korištenjem energije sunčeva zračenja. Prikazati će se primjena suvremenih informacijskih i WEB tehnologija za mjerenje, nadzor i dijagnostiku rada FN elektrana na daljinu, te tehničke značajke i dijagrami proizvodnje električne energije za jednu karakterističnu fotonaponsku elektranu.

Ključne riječi: energija sunca, fotonaponske elektrane, električna energija, emicija CO2, IT tehnologija, Sunny Web portal

1. Introduction

1.1. Energy of the Sun

Solar radiation received at the top of the atmosphere is terminated extra-terrestrial radiation or potential insolation. For a mean Earth-Sun distance, the intensity of solar radiation is 1367.7 W/m^2 (Geiger, 2003). Passing the atmosphere, potential insolation decreases depending on atmospheric condition. Maximal Sun radiation on Earth surface vertical to radiation is approximately 920 W/m^2 . Due to Earth rotation, solar radiation distributes on Earth surface in average up to 230 W/m^2 daily, which is resulting in average of 5.52 kWh/m² of energy, depending on the insolation duration (geo. width, season, atmosphere...), (Sljivac, 2013). Fig. 1. shows the annual solar radiation at the Earth's surface, compared with an annual consumption of energy in the world and fossil (coal, oil, gas) and nuclear fuel (uranium) reserves (Majdandzic, 2010).

Figure 1 Comparison of energy obtained by annual solar radiation and energy consumption as well as fossil reserves



Source: Majdandzic, 2010

1.2. The basic of solar cell

A solar cell is a solid-state electrical device that converts the energy of light directly into electricity using the photovoltaic effect.



Figure 2 Cross section of solar cell (Honsberg et al. 2014)

Source: Honsberg et al. 2014

The process of conversion first requires a material which absorbs the solar energy (photon), and then raises an electron to a higher energy state, and then the flow of this high-energy electron to an external circuit (Honsberg et al. 2014). A PV module consists of a number of interconnected solar cells encapsulated into a single, long-lasting, stable unit. The key purpose of encapsulating a set of electrically connected solar cells is to protect them and their interconnecting wires from the typically harsh environment in which they are used. A bulk silicon PV module consists of multiple individual solar cells connected, nearly always in

series, to increase the power and voltage above that from a single solar cell. Combinations of modules are referred to as an array. Figure 3 shows this distinction between cells, modules, and arrays (Sljivac et al. 2014).



Figure 3 Photovoltaic cells, modules, and arrays

The efficiency is the most commonly used parameter to compare the performance of one solar cell to another. Efficiency is defined as the ratio of energy output from the solar cell to input energy from the sun. Larger cells and modules tend to have a lower efficiency. The efficiency of different solar cell technology as a function of cell area is presented in Fig. 4.



Figure 4 The efficiency of different solar cell technology as a function of cell area (Honsberg et al. 2014)

Source: Honsberg et al. 2014

Three most commonly encountered configurations of PV systems are (Sljivac et al. 2014):

- Systems that feed power directly into the utility grid
- Stand-alone systems that charge batteries, perhaps with generator back-up,

• Applications in which the load is directly connected to the PVs as is the case for most water-pumping systems.

2. Solar radiation and photovoltaic electricity potential

The European solar radiation database was developed using a solar radiation model and climatic data integrated within the Photovoltaic Geographic Information System (PVGIS). In Fig. 5, yearly sum of global irradiation on optimally inclined surface for European countries is presented. Over most of the region, the data represent the average of the period 1998-2011, however, north of 58° N, the data represent the 10-years average of the period 1981-1990. All data values are given as kWh/m². The same colour legend represents also estimated solar electricity [kWh] generated per year by a PV power plant with rated power of 10 kWp, with photovoltaic modules mounted at an optimum inclination.



Figure 5 Photovoltaic solar electricity potential in European countries (Huld et al. 2012)

Source: Huld et al. 2012

In Fig. 6 yearly sum of global irradiation on optimally inclined surface for Croatian region Slavonia and Baranja is presented. As can be observed in Fig. 5, the value of insolation in region Slavonia and Baranja is less than in Southern part of the Croatia. But, in comparison to Germany and other countries that are north of Croatia and well known by the use of PV, the region of Slavonia and Baranja has grater photovoltaic solar electricity potential.



Figure 6 Photovoltaic solar electricity potential in Slavonia and Baranja

3. PV systems installed by "Solar projects Ltd"

Solar Projects Ltd. is a company specialized in the development of projects in the field of renewable energy, with special emphasis on the exploitation of solar energy. At this point, the company Solar Projects has successfully connected 78 solar power plants in the distribution network, and in the next few months it is planned commissioning of another 40-50 solar power plants. In 2013, the company received "Green Mark-sign of Excellence, given by Croatian Association for Energetics. Locations of 61 PV power plants installed by company Solar Projects in Slavonia and Baranja are presented in Fig. 7.

Baranja

Figure 7 Locations of 61 PV power plants installed by company Solar Projects in Slavonia and Baranja

Source: Solarni projekti d.o.o.

Web application with a database of PV power plants characteristics and associated location on Google Map is made. In Fig. 8 PV power plant Photovoltaica 1 in Virovitica with rated power of 120 kW is presented.



Figure 8 Location of PV power plant Photovoltaica 1 in Virovitica

Source: www.solarniprojekti.hr

Table 1 shows total installed capacity and the production of PV power plants installed by Solar Projects company in Slavonia and Baranja until February 2014. Furthermore, CO_2 emission reduction is calculated. If total production of 732 840 kWh was produced in the coal power plants in Croatia, the amount of 636,11 tons of CO_2 would be emitted in atmosphere. If the average emission of CO_2 per kWh produced power for generation mix of different power plant technology in Croatia is taken into account, total emission reduction equals 218,39 tons. Average emission for coal power plants and average emission for power plant generation mix in Croatia in period of 2008-10 are taken from literature (IEA 2012).

company, and estimated CO ₂ emission reduction					
Rated power	Number of PV power plants	Total production [kWh]	CO ₂ emission reduction	CO ₂ emission reduction	
			[tons]	[tons]	
			(average emission in	(average emission in	
			Croatia for coal power	Croatia for power plant	
			plants in period of 2008-	generation mix in period of	
			10 equals 868 g/kWh)	2008-10 equals 298 g/kWh)	
10 kW	33	260 544	226,15	77,64	
25 - 30 kW	27	434 440	377,09	129,46	
over 30 kW	1	37 856	32,86	11,28	
Total:	61	732 840	636,11	218,39	

Table 1 Total installed capacity and production of PV power plants installed by Solar Projects company, and estimated CO₂ emission reduction

Source: Authors 'calculation

4. Sample case of PV power plant Photovoltaica 1

4.1. Technical data

An example of one of the 61 power plants installed in Slavonia and Baranja is solar power plant Photovoltaica 1, which is located on the roof of the storage building in Virovitica. The power plant is divided into 32 rows, with 10, 15, 20, 21 PV modules in each row. A total of 576 photovoltaic modules is installed, with individual power of 240 W. The total peak of PV arrays is 138.24 kW and the maximum output power is 120 kW. The modules are placed directly on the tin roof, with a roof pitch of about 6° in the north side of the roof and part of the roof on the south side of the building with a roof pitch of 30°. Modules are type Ecoline 60/LX-240P German manufacturer Luxor, consisting of 60 series connected polycrystalline silicon cells measuring 156×156 mm. Dimensions modules are $1640 \times 992 \times 45$ mm and weight of the module is 21 kg. Other characteristics of the photovoltaic modules are given in Table 2.

Short circuit current	Isc (A) = 8,49 A
Open circuit voltage	Uoc (V) = 37,76 V
Rated current	Impp $(A) = 7,95 A$
Rated voltage	Umpp $(V) = 30,38 V$
Max. system voltage	U(V) = 1000 V
Nominal operating cell	$t (^{\circ}C) = 47 \pm 2 ^{\circ}C$
temperature	
Efficiency	$\eta = 14,85/14,30$ %
Temperature range	- 40 °C - + 85 °C
Max. pressure load	5400 Pa

Table 2 Characteristics of the photovoltaic module Luxor EcoLine 60/LX-240P

Source: Authors 'calculation

Inverter covers entire operating range of the photovoltaic field in all conditions. 8 inverters of manufacturer SMA, type SUNNY Tripower 15000TL are installed. The inverter has the power rating of 15 kW and maximum efficiency 98.2% with an embedded security systems to protect the isolated operation, and overcurrent and overvoltage protection, and has a wireless Bluetooth connection.

4.2. Electricity generation monitoring

As the central communication interface, the Sunny WebBox connects the PV plant and its operator. The Sunny WebBox collects and documents all data of the connected devices, thus permitting interruption-free monitoring of the PV plant. The operator can access all the data stored in the Sunny WebBox via an Internet connection or a GSM modem. The Flashview presentation software and the Sunny Portal website can be used to edit data or graphically display stored data. This means that operators can see the yields from their plant both in the local network and via the Internet at any time using Flashview and the Sunny Portal.

Using Sunny WebBox remote control system, all relevant daily, monthly, annual parameters of the electric power generation can be monitored. In Figures 9. and 10. examples of the daily production of electricity in summer and autumn day are presented.



Figure 9 Production of PV power plant in summer day (29th August)

Source: www.sunnyportal.com



Figure 10 Production of PV power plant in winter day (6th January)

Source: www.sunnyportal.com

Electricity production in kWh for each day in September is presented in Fig. 11. In Fig. 12 monthly yield expectations and actual generation are presented.



Figure 11 Production of PV power plant in September (2013)

Source: www.sunnyportal.com



Figure 12 Monthly yield expectations and actual generation

Source: www.sunnyportal.com

5. Conclusion

In this paper, the basics of converting solar energy into electricity are described. Furthermore, the application possibilities of solar energy conversion according to insolation maps of Eastern Croatia are analysed. Due to its position in Europe, the region of Slavonia and Baranja has grater photovoltaic solar electricity potential than some of the northern European countries that are well known by the use of PV. Producing electricity from PV power plants causes significant savings in carbon emission due to reduction of generation in thermal power plants. In this paper, sample case of PV power plant is presented. Furthermore, application of modern ICT and web technologies for distance measuring, monitoring and diagnostics of PV power plant are presented.

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