EXPLOITING SOLAR ENERGY WITH PHOTOVOLTAICS

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Abstract: Energy balance of a solar panel is considered in relation to its efficiency. The monthly, seasonal and yearly means of solar radiance exposures are presented in a form of geo-referenced maps for whole Slovenia with a spatial resolution 100 m x 100 m, as well as the diagrams of the optimal tilts and orientation of solar collectors for selected places in Slovenia. In rough relief, not only the whole landscape is divided into sunny and shady parts, but also different sky-view factors influence strongly the diffuse part of radiance exposure. The trend of increasing global solar radiance exposure during the last few decades can partly be explained with the trend of the reduced fog occurrence over Slovenia.

Fotonapetostno izkoriščanje sončne energije

Kjučne besede: sončno obsevanje, Slovenija, fotovoltaika

Izvleček: Energijska bilanca fotonapetostnega modula je pogojena tudi z njegovim izkoristkom. Mesečna, sezonska in letna povprečja sončnega obsevanja so predstavljena na geografski karti z resolucijo 100 m x 100 m za celotno Slovenijo. Prav tako so podani diagrami optimalnega naklona in orientacije fotonapetostnih modulov za izbrane kraje v Sloveniji. Na razgibanem terenu pokrajina ni razdeljena samo na senčni in osončen del temveč tudi glede na različne vidne kote neba, ki močno vplivajo na difuzni del obsevanja. Trende povečevanja sončnega obsevanja v zadnji dekadi lahko razložimo delno tudi z zmanjšanjem pojava megle v Sloveniji.

1 Introduction

The natural resource for exploiting solar energy is of course solar irradiance that differs from place to place due to astronomical and weather related factors. While astronomical part can be well described with analytical equations, the meteorological part should be determined with a help of the measured data as well as using the results of meteorological models. The most important is of course the solar irradiance (power density), or radiance exposure (energy density, accumulated in a certain time, for example in a day). The next most important is air temperature, affecting the energy balance of solar collectors, followed by other parameters that influence heat exchange between collectors and their environment, like wind, precipitation etc., resulting in temperature of collector. Temperature is important as efficiency of PV cells diminishes with temperature.

In this paper are thus presented the factors of energy balance of a solar panel, the methodology for obtaining georeferenced solar radiance exposures in a horizontal resolution of 100 m x 100 m, and the optimal tilts and orientations of surfaces with the highest radiation exposures.

2 The data

2.1 Solar energy data

Solar energy is not measured for a long period at many meteorological stations in Slovenia since most of the pyranometers, measuring global solar irradiation, were installed only in the last ten or fifteen years. Therefore, the time period for climatology of solar radiance exposures do not span over the 30-year period, which comprises the climatologically established standard that ensures the desired stability and representativeness of the measured data. Namely, if we want to consider the 30-year period we would have to hold back on our study and the publishing of results for the next 15 years. Due to the requirements of such data, the study was only performed on 10-year-long data sets.

As the exploitation of solar energy depends on the proportion between the direct and the diffuse part of irradiance, it is important to know both. The relief of Slovenia is rough and so not only that the whole landscape is divided into some parts that are more exposed to the sun and other more shady ones; the relief is also significant for the diffuse part of radiation. The diffuse radiation from the sky is reduced by the sky-view factor, which is the visible proportion of bright sky that also contributes an important part to insolation. The direct part of quasi-global radiance depends mostly on the incidence angle, which is defined by astronomical and surface parameters, as well as the horizon of the surrounding relief. The obstacles on horizon influence the effective possible duration of solar radiation. All these influences were included in our own model /1/ for computing quasi-global solar irradiance and radiance exposure with a spatial resolution of 100 m x 100 m (based on a digital relief model of Slovenia, © Surveying and Mapping Authority of the Republic of Slovenia).

2.2 Other meteorological data, influencing the efficiency of the PV panel

In this subsection we are going to explain how the environmental data influence efficiency of the PV panel. It is known that efficiency diminishes with the increasing temperature

T /e.g. 2/. The temperature of cells or a whole panel as a bulk is the result of the energy exchange between the panel and its environment. The first are the conduction and the convection, depending on panels and on environmental temperature, with exchange coefficients that depend also on wind and turbulence. Next is the infrared radiation leaving the panel (depending on 4^{th} power of panels temperature) and infrared radiation from the environment to the panel, depending on 4^{th} power of temperature of the environment (above the panel is the air having in clear sky conditions the bulk emissivity of approx. 0.7). In addition, eventual precipitation or dew has energetic consequences via the latent heat of evaporation. Therefore, for a detailed consideration of factors of panel's efficiency besides the solar irradiance also these heat exchanges should be taken into account.

3 Global and quasi-global solar radiance exposures

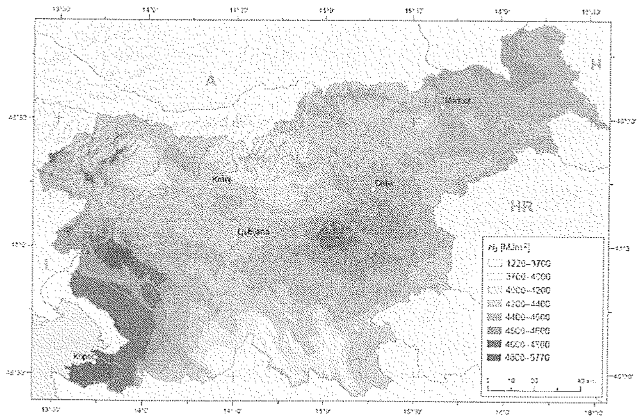

Fig. 1: Yearly mean of the global radiant exposure for Slovenia /1/.

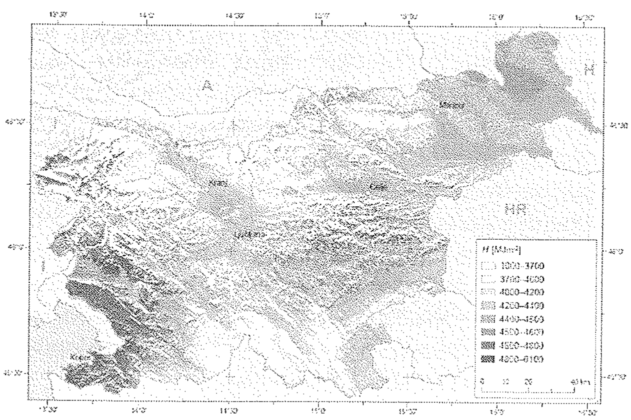

Fig. 2: Yearly mean of the quasi- global radiant exposure for Slovenia /1/.

Monthly charts of the global (on horizontal receiving surface) and quasi-global solar radiant exposure (of differently tilted and oriented surfaces) were computed, as well as seasonal and yearly charts. As two examples we show here the yearly chart of the global (in a 1 km x 1 km horizontal resolution; Fig. 1), and the quasi-global exposures (in a 100 m x 100 m horizontal resolution; Fig. 2) for Slovenia. The sunny and shady slopes are evident at first glance. The radiant exposure could even be some 20 % higher on the sunny slopes in comparison with the global exposure of horizontal surfaces. The shady slopes differ from the horizontal areas even more (even by 70 %). This asymmetry is mainly caused by the effect of the relief on the direct radiation - shady slopes experience a less favourable incidence angle of the sun and are often in the shade (when they only receive a diffuse part of radiation), while the sunny slopes are only influenced by a greater inclination angle of the sun, while in general they are not shadowed.

4 The optimum orientation and tilt

The orientation and slope of a collector can contribute an important increase to the energy collected in the exploitation of solar energy. The primary factor of sensible exploitation is, of course, the placement of the collector in a sunny place in order to prevent shadows from obstacles in the nearby and more distant vicinity. Then the optimal inclination and orientation has to be established: one can assume that the collector should be oriented towards the south and that the summer inclination (with the sun high in the sky) should be smaller than the winter inclination. However, a careful analysis also offers some less expected and even surprising results (Fig. 3).

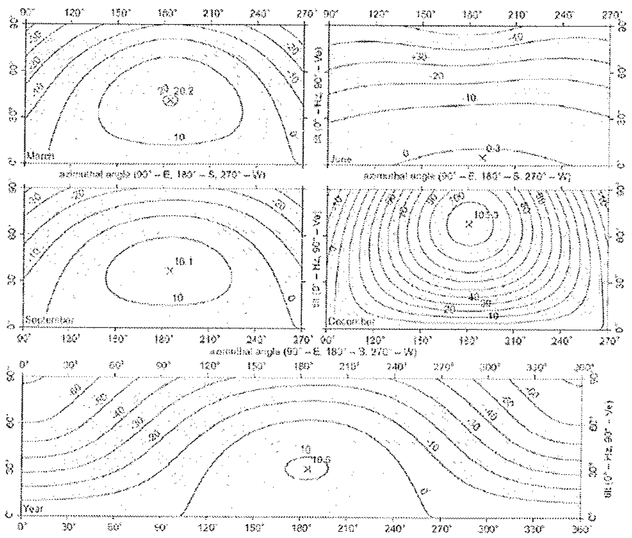

Fig. 3: Contour plots of relative PV array energy yield regarding the horizontal surface as a function of fixed orientation and tilt for March, June, September, December and the whole year for Portorož in the Mediterranean part of Slovenia /3/.

For example, mainly during the cold part of the year the basins and plains of the lowlands are often foggy or covered by low stratus cloudiness that clears only late in the morning or even in the afternoon. An orientation slightly to the West provides a better incidence angle for the stronger afternoon direct radiance exposure. There are regional differences in optimal inclination: the optimal value in the Mediterranean area is, for instance, higher than in the north-eastern area. In June, when the towards South tilted collectors do not receive direct irradiance in morning and evening hours, when the sun is not yet, or no more on the southern part of the sky, tilting the collector is not very appropriate as regards the daily sum of radiant exposure.

The above consideration is general - considering only the solar radiance exposure of the receiving surfaces. Especially with PV panels, another factor should be taken into account, being connected with the dependence of its efficiency on temperature. In morning hours, panels are normally cold and thus their efficiency is higher than in afternoon hours when the panels may warm up to 70 °C. With such an increase of the panel's temperature its efficiency drops in outdoors conditions from over 11 % down to some 10 % - relatively that means for one tenth; Figure 4, /4/. This degrease in efficiency prevails over the slightly higher irradiances in afternoon hours. Therefore, specifically for PV panels orientation slightly towards east may perform better.

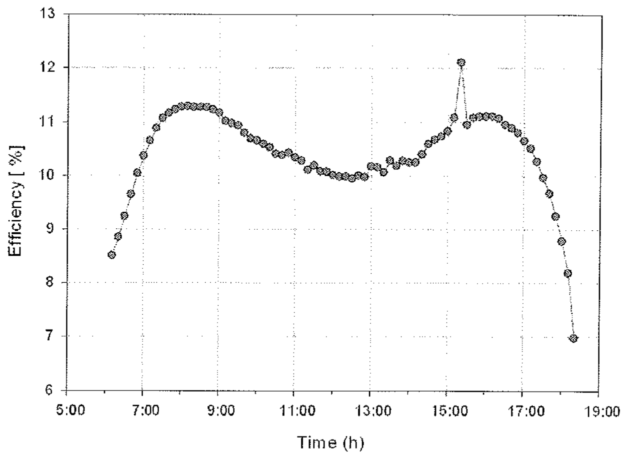

Fig. 4: PV panel efficiency during the clear sky day /4/

5 Trend in last decades

The trend of increasing global solar radiance exposure (Fig. 5) can partly be explained by the trend of the reduced fog occurrence over Slovenia /5/, yielding to the increase in solar energy seen during the last few decades.

5 Conclusions

The results of our present study can be compared with the ESRA - the European Solar Radiation Atlas /6/, as well as with a study for Slovenia from some decades ago /7/. The comparison with the ESRA shows that in December almost the whole of Slovenia is in the class 2.7-3.6 MJ/m^2 daily, except for the Julian Alps that are in the class 3.6-4.5 MJ/m^2 daily - our results show more details and for the basin the interval 2.3-2.9 MJ/m^2, the majority in an interval 2.9-

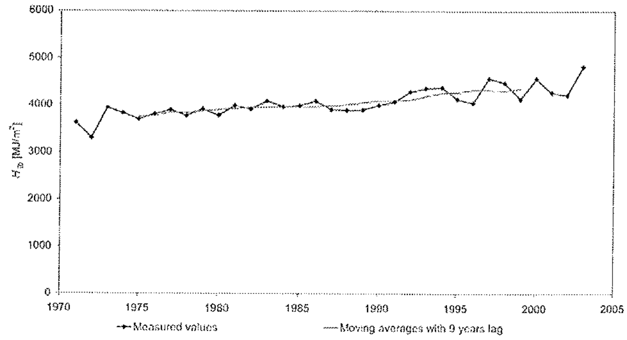

Fig. 5: Trend of solar global radiant exposure for Ljubljana in last decades /1/.

3.9 MJ/m^2, and with some maxima (mainly in the mountains) over 5 MJ/m^2 daily. In June, ESRA global solar radiance exposure in Slovenia is in four classes: the narrow coastal part 20.7-21.6 MJ/m^2, the rest of the Mediterranean part of the country 19.8-20.7 MJ/m^2, a belt from the Julian Alps to the SE and to the NE of the country with 18.9-19.8 MJ/m2, and the rest with 18.0-18.9 MJ/m^2 daily. Our results range from 5.8-24 MJ/m^2. So both of the results largely agree to a certain extent - but our study provides much more details.

Acknowledgements

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References

/1/ Kastelec D, Rakovec J, Zakšek K. Sončna energija v Sloveniji (Solar energy in Slovenia). Ljubljana (SI): Založba ZRC SAZU, 2009.

/2/ Carlson, DE, Lin G, Ganguly G. Temperature dependence of amorphous silicon solar cell PV parameters. IEEE Phot Spec C 2000; 28; 707-712.

/3/ Rakovec J, Zakšek K. Sončni obsevi različno nagnjenih in različno orientiranih površin (Solar radiance exposures of differently tilted and differently oriented surfaces). EGES 2008; 2: 93-95 and 3: 65-69.

/4/ J. Kurnik, M. Jankovec, K. Brecl, M. Topič, 2008: Development Of Outdoor Photovoltaic Module Monitoring System. Informacije MIDEM 38, 75-80.

/5/ Petkovšek Z., 1996: Urban climate change on a fog case. Proc. 14th Int. Cong. Biometeorol, 1-8 Sept 1996, Ljubljana, 306-310.

/6/ ESRA, 2000 - Schramer, K. and J. Greif, 2000: The European Solar Radiation Atlas. Ecole des Mines de Paris. Vol. 2: xii+296 pp.

/7/ Hočevar, A. in sod., 1980: Razporeditev potenciala sončeve energije v Sloveniji. VDO Biotehniška fakulteta, VTOZD za agronomijo, (Ljubljana), 69 str.

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