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MOGUĆNOSTI KORIŠTENJA EUROPEAN SOLAR RADIATION ATLASA NA PRIMJERU ANALIZE DNEVNOG PRIVIDNOG KRETANJA SUNCA

THE POSSIBILITIES OF THE EUROPEAN SOLAR RADIATION ATLAS USAGE ON THE EXAMPLE OF DAILY OSTENSIBLE SUN MOVEMENT ANALYSIS

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Stručni članak

Sažetak: *Primjena European Solar Radiation Atlasa (ESRA) u analizama dnevnih kretanja Sunca po nebu i njegovih učinaka je rasprostranjena u svim inženjerskim strukama. Matematički odnosi visine i azimuta Sunca u određenom trenutku, defniranom datumom i vremenom, mogu se npr. u elektrotehnici koristiti za proračune proizvodnje i upravljanje fotonaponskim postrojenjem. Rezultati na mjernim stanicama širom Europe daju empirijske odnose zračenja, vremena i proizvodnje električne energije. U ovom radu je dan pregled modela za prividno kretanje Sunca kroz dnevnu analizu visine i azimuta Sunca, te analiza proizvodnje fotonaponskog postrojenja na krovu zgrade Visoke tehničke škole u Bjelovaru pomoću web sučelja implementacije ESRA modela za spomenutu primjenu – PVGIS (Photovoltaic Geographical Information Systems).*

Ključne riječi: *azimut Sunca, visina Sunca, fotonaponsko postrojenje, proizvodnja električne energije, empirijski model, PVGIS*

Professional paper

Abstract: *The application of the European Solar Radiation Atlas (ESRA) in daily Sun motion in sky analysis and its effects is widely spread in all engineering professions. Mathematical relations for Sun azimuth and height in specified moment, defined by date and time, can, for instance, be used in electrical engineering calculations of energy production and control of photovoltaic plants. The results obtained at measuring stations across Europe produce empirical relations between irradiation, time and electrical energy production. In this research a model of ostensible Sun movement trough daily analysis of its height and azimuth, and the analysis of production of integrated photovoltaic plant on the roof of the Technical College in Bjelovar with the web interface implementation of ESRA model for specified application – PVGIS (Photovoltaic Geographical Information Systems) are presented.*

Key words: *Sun azimuth, Sun height, photovoltaic plant, electric energy production, empirical model, PVGIS*

1. INTRODUCTION

The analysis of natural resources and hydrometeorological data bases is currently integrated in many different professions; from agricultural analyses and spatial planning to complex planning, design and exploitation of electric energy and industrial plants. Hydrometeorological data bases are stored for years and used for analyzing climate changes on Earth. The amount of data and the distribution of measuring stations ensure highly accurate results and conclusions regarding the changes that arise from pollution. Scientific research in areas in which a rapid increase in the quality of planning, design and resources exploitation has been noticed could not have been based on statistical data from the past because such data did not exist. Therefore, such research is orientated towards the existing data infrastructure that is available, namely the hydrometeorological data in the first place.

One of the approaches to collecting, analyzing and generating universal sets of open type results is ESRA [1], which is completely adapted to implementation by users who are not fully competent in the area whose results they use. Being integrated as a complete software solution, ESRA involves a basic measuring data base and various type displays of directly or indirectly calculated results. For the calculation of these results various existing and well-known models were made and checked.

2. THE EUROPEAN SOLAR RADIATION ATLAS

The zone covered by the ESRA data base is limited to the area of Europe 30° in the east to 70° in the west, as well as from 25° do 75° in the north. The main research area is Europe. Figure 1 represents the research area in the canonical projection with x-y coordinates.

Figure 1. Data coverage area in ESRA

The entire research generated two fundamental results: data base and ESRA software package. The data base consists of results collected in the period between 1.1.1981 and 31.12.1990 from measuring stations distributed across the whole observed area, especially densely in Switzerland.

According to the measuring results digitalized maps of the transparency factors were made, based on which maps of overall, dispersed and direct irradiation were made. Maps were made in the 10x10 km² raster, and the reference point is positioned in its center. The input data for making digital maps of various characteristics of a chosen location are geographical position, height above mean sea level, overall, dispersed and direct solar irradiation, transparency factor, biomass growth factors and various types of general data such as borders and names of states etc. The other set of data refers to parameters that are not available at all measuring stations, i.e. the number of sun hours, total irradiation, Ångström coefficients a_m and b_m, environment temperature, air pressure, humidity and amount of precipitation. Spatial analysis was carried out and the results were presented using several different models for the calculation of spatial characteristics in the environment of a selected location.

The available sets of data are shown in several different formats, but for some measuring stations not all formats are available. Detailed hydrometeorological data measured at 90 measuring stations are available in daily values, whereas six measuring stations measured them in hours and one station in half-hour periods. Monthly values are available for a large number of measuring stations distributed across Europe and its surroundings. Monthly mean values of the number of sun hours are, for instance, available from 695 measuring stations.

The use of the ESRA software is adapted to many different professional and implementations. It provides engineers and architects with the possibility of gaining insight into solar resources at required locations for the purpose of dimensioning the equipment, producing energy, ensuring available resources for buildings etc. Another user group refers to agronomists, foresters, landscape and town planners who require various hydrometeorological data such as air temperature, air humidity, precipitation amounts etc. A special user group includes researchers involved in various research types, e.g. for scientific causes in photovoltaic production of electric energy and climate research and education. Furthermore, ESRA is frequently used as an additional source of data in professions whose needs are not directly related to these data, but require them for more detailed processing of other significant topics, e.g. in politics and journalism. An example of such implementation is the PVGIS software that, based on network data bases, assesses the possibilities of photovoltaic plant production on various locations in Europe.

3. OSTENSIBLE SUN MOVEMENT MODELING

Ostensible Sun movement modeling, observed from a certain location, is derived from geometrical relations between Earth and Sun and time periods in which movements take place. Linear models take into account ideal movement trajectories, but do not present the accurate relation between bodies, i.e. parameters that describe that movement.

The time of sunrise and sunset is always equally distant from noon if it is defined that noon is the moment in which Sun passes over the meridian that goes along a defined location. Thereby it is clearly defined that this is valid for every location λ and its referential λ_{st}. Furthermore, all locations observed in this way that are situated on a particular meridian will have the same noon and the time of sunrise and sunset. However, the conventional time measurement is adapted to more practical forms for everyday usage that especially refer to time zones in intervals of one full hour, which is called *civil time* and is marked with t_{mj}. If input data are set in civil time, it is necessary to translate them to time defined by ostensible Sun movement observed from a defined location using the equation (1), which is called *solar time* and is marked with t_s. Summer and winter time calculation is taken into account by means of the additional constant C. Time correlation Δt_v, shown in figure 2, represents non-linearity in geometrical relations between Earth and Sun.

$$t_s = t_{mj} + \Delta t_v + \frac{\lambda - \lambda_{st}}{15} - C\,[h] \tag{1}$$

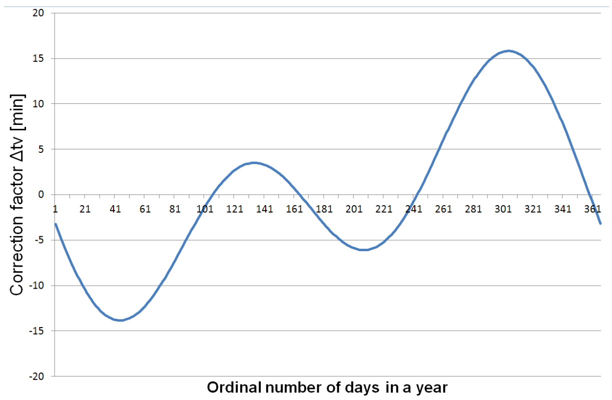

Figure 2. Equation of time according to the ESRA model

The imperfection of the Earth movement trajectory around Sun and the position of rotation axis relative to this trajectory alter relative geometrical relations, depending on the position of Earth on the trajectory. The angle distance of the line passing through the center of Earth and the center of Sun from the equator is called declination. Declination determines the Sun height at noon for a given location. During summer declination is positive, so in the northern hemisphere Sun has a larger angle height at noon than the annual mean value , while during winter declination is negative, so Sun is lower than the annual mean value.

By knowing the latitude φ, Sun hour ω and declination δ the mathematical position of Sun's center in the sky may be calculated using azimuth angles and the height. Sun's height γ_s is the angle between the horizontal plane in the observation position and the line that connects Sun's center and the observation point. The value is calculated by the equation (2). Sun's azimuth α_s is shown referentially towards south where it amounts to 0°, and towards north across east in negative values to -180° and across west in positive values +180°. The value is calculated by equations (3) and (4).

$$\gamma_s = \sin^{-1}(\sin\varphi \cdot \sin\delta + \cos\varphi \cdot \cos\delta \cdot \cos\omega) \quad (2)$$

$$\cos\alpha_s = \frac{\sin\varphi \cdot \sin\gamma_s - \sin\delta}{\cos\varphi \cdot \cos\gamma_s} \quad (3)$$

$$\sin\alpha_s = \frac{\cos\delta \cdot \sin\omega}{\cos\gamma_s} \quad (4)$$

4. ESRA MODEL RESULTS

The realization of the ESRA model of Sun movement was carried out in MS Office Excel. Input data consist of geographical coordinates of the observed location and the date and time for which Sun's position in the sky is calculated. Based on these data Sun's height (figures 3 and 5) and Sun's azimuth (figures 4 and 6) may be calculated at any given moment.

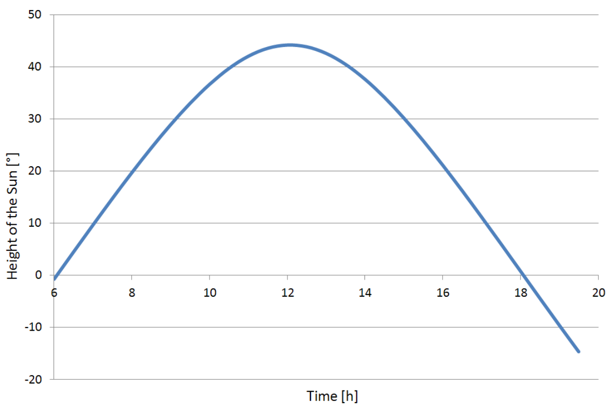

Figure 3. An example of Sun's height calculation results on 21st March 2012

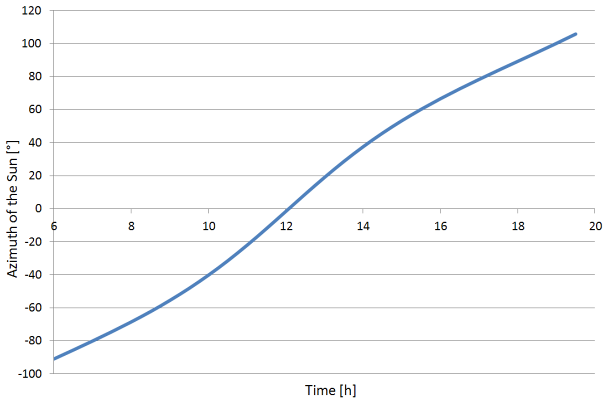

Figure 4. An example of Sun's azimuth calculation results on 21st March 2012

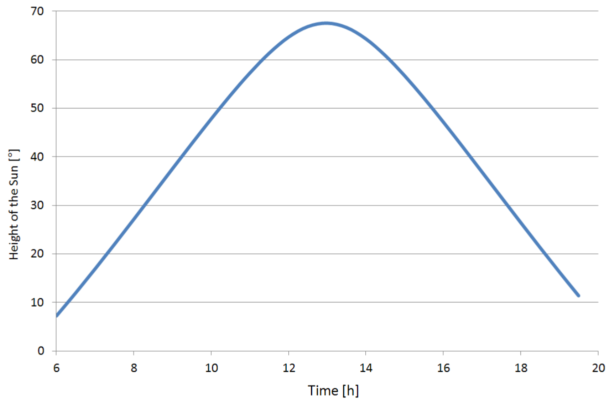

Figure 5. An example of Sun's height calculation results on 21st June 2012

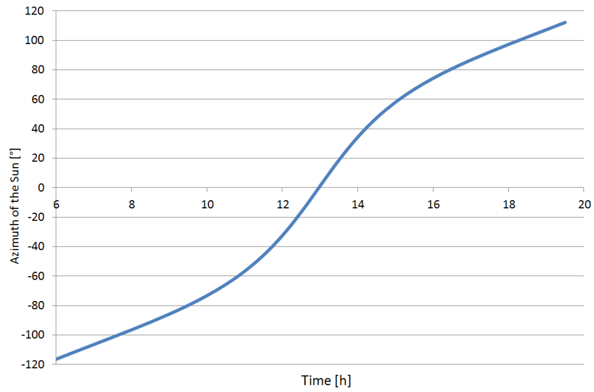

Figure 6. An example of Sun's azimuth calculation results on 21st June 2012

On the example of spring equinox and summer solstice differences in the Sun's trajectory in the sky on various days in the year may be noticed. Winter days have significantly lower daily amplitude of Sun's height than the summer ones. Due to the equal appearance of the daily diagram of Sun's height, this fact results in later sunrise and earlier sunset in winter than in summer.

Such analyses are also the foundation for more complex calculations, e.g. using conventional analytical models for calculating electric energy production at photovoltaic plants. The mathematical model that derives from [1] is PVGIS [2], shown in figure 7, which uses measurement results and empirical relations from the very measuring stations that are described in [1].

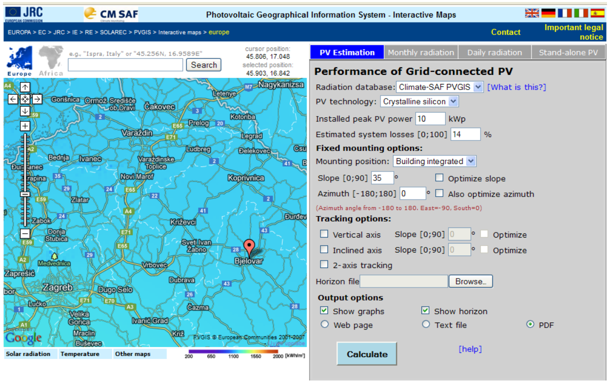

Figure 7. On-line PVGIS interface

The location of the photovoltaic plant on the building of the Technical College in Bjelovar (location 45°54'9" in the north 16°50'31" in the east, [3]) has the maximum installed power amounting to 10 kW. An example of monthly results of individual modeling of PVGIS electric energy production shown in table 1 refers to the production within an average day in the month (E_d) and the average total monthly production, (E_m) of electric energy by the photovoltaic plant. Apart from the energy results, data related to the average monthly irradiation onto the horizontal (H_d) and inclined plane (H_m) are generated as well. PVGIS anticipates the electric energy production in average months for various operating modes, as shown in figure 8, and in an average year, as shown in table 2. The optimum parameters of this photovoltaic plant are empirical data generated from PVGIS network data bases, and are different for various operating modes. Thus, the orientation optimum for the fix operating mode refers to azimuth amounting to -1° and inclination amounting to 34°, whereas at directing the azimuth the optimum inclination amounts to 53°.

Table 1. The production of electric energy by a photovoltaic plant in the fix operating mode (-1°, 34°)

	E_d / kWh	E_m / kWh	H_d / kWh/m²	H_m / kWh/m²
January	13.30	413	1.68	52.2
February	23.30	652	3.00	83.9
March	31.50	977	4.22	131
April	38.10	1140	5.25	158
May	42.20	1310	6.00	186
June	42.40	1270	6.08	182
July	43.10	1340	6.19	192
August	41.10	1270	5.94	184
September	33.50	1010	4.69	141
October	25.90	803	3.51	109
November	16.00	479	2.02	60.7
December	11.30	351	1.40	43.5
average month	30.20	918	4.17	127

Tabela 2. Annual electric energy production by a photovoltaic plant for various operating modes

	Fix [kWh]	Azimuth [kWh]	Inclination [kWh]	Biaxial [kWh]
year	11000	14900	14900	15200

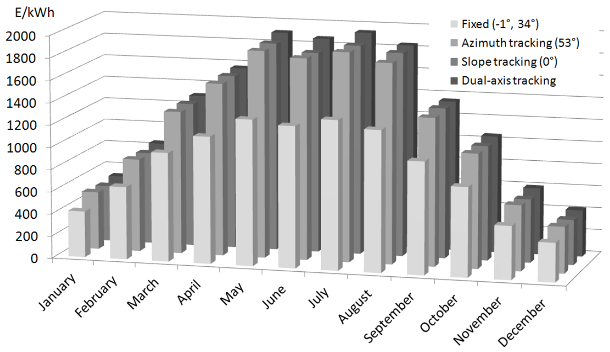

Figure 8. Comparison of modeled productions according to PVGIS for various operating modes

From the obtained results it may be concluded that the largest contribution in the energy produced by a photovoltaic plant is achieved by implementing the shift routing as opposed to the fix operating mode. The gain obtained by implementing biaxial directing is insignificant, so it is economically unacceptable.

5. CONCLUSION

Empirical mathematical model derived from measurement results at measuring stations across Europe are used for modeling purposes in all areas of engineering. Although they do are not subject to strict mathematical relations, i.e. they have no specified relations between all parameters, a certain accuracy of results obtained by such models may be expected due to measured data bases. The PVGIS model that arises from measurement results at measuring stations in Europe is frequently used in modeling photovoltaic plants. The results are taken as general and describe the actual state quite well.

5. REFERENCES

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[2] http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php

[3] https://maps.google.hr/

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