SOLAR ENERGY IN SERBIA AND THE WORLD, AND MODEL OF GLOBAL SOLAR RADIATION ON HORIZONTAL SURFACE

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Abstract: Solar energy , in direct and indirect forms, is the source of almost all energy on Earth. By applying advanced technology to ensure that the action of collecting, storing and transporting energy, solar energy could soon find more effective and wider application in all human activities. This paper presents the data clearly show that Serbia has the resources of solar radiation well above the European average and the model that allows the determination of the intensity of global solar radiation at the desired location in the given time. By comparing the results with measured data from the meteorological station was established that there is a match with a maximum measured radiation corresponding to the global solar radiation during sunny days.

Keywords: *energy of solar radiation, extraterrestrial radiation, Matlab model*

1. INTRODUCTION

Production of electricity from photovoltaic cells is still economically significantly more expensive than the production of conventional energy sources. Photovoltaic cells have found significant application in the power supply isolated consumers of low power, to which economically profitable to build a distribution network (*EPIA*). Due to the nature of the diffusion of sunlight and low efficiency in energy conversion, solar systems consist of a large number of solar cells and cover vast areas. Depending on the type and characteristics of the photovoltaic cells for the production of 1 kW of energy, needed surface area of solar panels of 3.5 - 8 m^2 or more (*Greenpeace International*). The usefulness of PV solar cells ranges from a few percent to forty percent. Other energy that is not converted into electricity is mainly converted into heat and thus warms the cell. Increase teperature of solar cell affect the usefulness of reduced PV cells (*Luque).* Another way to create electrical energy with the help of solar thermal generators whose work is based on the heat. With the help of solar panels that perform the transformation of solar energy into heat, accepted Solar energy is focused on a pipe or vessel containing a liquid or solid, that has the role of heated water, or in their own waters. Thus, the solar energy collected from large area concentrates almost one point and creates a very high temperature. The water is heated at a temperature up to 1500 ^{0}C (*PV Status Report*). Resulting water vapor, which is under pressure, is used for mechanical work, i.e. launch classic steam turbine, which converts mechanical energy into electrical energy. Collectors are mobile devices that monitor the movement of the sun and collect the maximum amount of energy during the day. From the aspect of environmental protection Solar energy is a reliable and clean source of energy (*Uredba*). Technology utilization of solar energy does not cause pollution, does not destroy the Earth's surface and does not require difficult and expensive extraction process. Does not create noise. Visual pollution is a subjective assessment. The impact on the environment of the production of silicon for solar cells is insignificant. However, the highest insolation it's in those parts of the world which have the lowest energy consumption (*Kartick*). The problem is what to do at night when the Sun is not shining or when shining insufficient intensity, when our energy is most needed. It is necessary to find a way to collect solar energy where there is enough, then stored and then transported to where it is needed and used when needed.

2. UTILIZATION OF SOLAR ENERGY

Solar cells produce a voltage of 0.5 - 0.7 V with a current density of about several tens mA/cm^2, depending on the intensity of solar radiation, and the radiation spectrum. The usefulness of photovoltaic (PV) solar cell is defined as the ratio of the electrical power provided by the PV solar cell and power solar radiation. Mathematically, this relationship can be defined by equation:

$$\eta = \frac{P_{el}}{P_{sol}} = \frac{U \cdot I}{E \cdot A} \qquad (1)$$

where in : P_{el} - electrical output power; P_{sol} - Power radiation (mostly solar); U - The effective value of output voltage; I - The effective value of the output current; E - Specific power radiation (in W/m^2); A – Area.

In laboratory tested the possibility of using high temperatures, obtained by concentration of the solar energy, for the initiation of a chemical reaction between carbon dioxide and methane in the presence of a catalyst. Gas resulting from the mixture of hydrogen and carbon monoxide, and can be stored and transported (*Jiang*).

$$CH4 + CO2 = 2CO + 2H2 \; ; \; \Delta H298 = 247 \text{ kJ / mol} \qquad \text{(a)}$$ (*Jiang*).

$2CO \rightarrow CO2 + C$; $\Delta H298 = -172$ kJ / mol (b) (*Ballarini*)

$CH4 \rightarrow C + 2H2$; $\Delta H298 = 75$ kJ / mol (c) (*Ballarini*)

Gas separation into constituent components releases energy that can be converted into electricity. Scientific works proposing various performances of metal catalysts, such as Ni and Co, or a noble metal such as Rh, Ru, Pd, Pt and Ir, which would support the chemical reaction (*Lima*), (*Tsipouriari*), (*Bhat*).

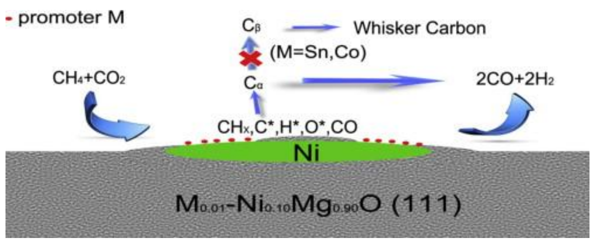


Figure 1: The adsorption of the reactants in the mixed metal catalyst

When adsorption traceable by dissociation of the reactant molecule broken the σ - connection. In many studies it has been proven that dissociative chemisorptions always precedes physical adsorption, which contributes to the weakening of the chemical bonds in the reactants.

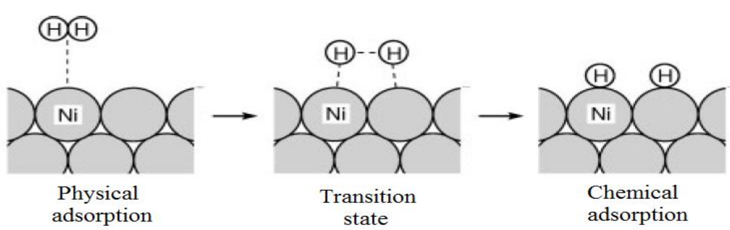


Figure 2: Physical adsorption, which contributes to the weakening of chemical bonds in the reactant, precedes dissociative chemisorptions

It is difficult to derive a general conclusion about the way the chemical binding of a substrate to catalyst, since it depends largely on the type of catalyst, temperature and degree of saturation of the active sites. Based on the IR spectra it was found that the molecular surface of the binding of CO to the catalyst metal may be carried out in different ways, wherein the origin of a linear complex is favored when the degree of saturation of plumb of the active sites.

Figure 3: Different ways of molecular CO binding to the surface of the metal catalyst

The greatest problem, however, is the deposition of carbon on the catalyst surface, which leads to blocking of active sites and reduced the deactivation of catalytic activity. Many researchers have dealt with the investigation and promoting properties of various catalysts (*Bitter*), (*Nurunnabi*), (*Khalesi*) and (*Arandiyan*). The problem can be solved and hydrogen gas. Hydrogen is not found in nature, in the free form, except in the highest levels of the atmosphere, but the composition has of different chemical compounds. Can be prepared from various substances, in various ways, but one possibility is the decomposition of water using the electrical energy (the electrolytic water). Another possibility is that the high temperature, resulting concentrations of solar energy, simply tear the molecule of water, without the use of photo-electrolysis. Hydrogen can be used as fuel for transport, to create heat and electricity, and as a medium of storing energy. Hydrogen offers the possibility of solar energy is converted into a portable form of energy and thus meets the needs of all sectors of modern society's energy. Since the development of solar energy application will depend on technological progress. Solar energy is still more expensive than the energy obtained by burning fossil fuels. Stricter laws in the field of environmental protection and guides recyclable materials in the construction of photovoltaic cells, could contribute to solar energy becomes cheaper energy.

3. MODEL INTENSITY OF SOLAR RADIATION

3.1.Extraterrestrial radiation

Power of solar radiation (luminosity) that is released from the surface of the Sun is equal to the product of the density of radiation, defined Stefan- Boltzmann law and the Sun's surface (*Bowden*) and is represented by the equation (2).

$$P_{Sun} = G_{Sun} \times A_{Sun} = \sigma T^{4} \times 4\pi R^{2}_{Sun} \qquad (2)$$

Power of solar radiation H0 that the sun shines through the imaginary surface at a distance D from the center of the sun according to the formula (3), is the quotient equal power solar radiation and surface field A_0 :

$$H_0 = \frac{P_{Sun}}{A_0} = \frac{R_{Sun}^2}{D^2} \sigma T^4 = \frac{R_{Sun}^2}{D^2} H_{Sun} \qquad (3)$$

The Earth orbits the sun in 365.25 days in a slightly elliptical orbit at an average distance of 149.5×10^6 km, with an average intensity of solar radiation, known as the solar constant H_{const}, is 1367 W/m^2. The intensity of solar radiation that Earth receives H_0 for the nth day of the year (*Radosavljević*), during its annual orbit around the Sun can be represented by the equation (4).

$$H_0 = H_{const}\left[1+0.033\cos\left(\frac{360(n-2)}{365}\right)\right] \qquad (4)$$

Earth's axis of rotation is parallel to the axis of rotation around the sun , but with it an angle of declination δ , which changes throughout the year ranging from +23.45° and -23.45° (*Keller*). This change affects the angle of declination to the point in the northern and southern hemisphere don’t receive the same amount of solar energy, except during the spring and autumn equinoxes. The value of the angle of declination of the nth day from the beginning of the year is shown in formula (5).

$$\delta = 23.45^0 \sin\left[\frac{360}{365}(n-1)\right] \qquad (5)$$

Since the Earth is round, sunlight does not fall under the same angle in all parts of its surface, both during the day and during the year. The angle of the sun's rays fall on a point of the earth's surface is called the elevation angle α. Who’s the Earth's atmosphere has a significant effect on the intensity of solar radiation introduces the concept extraterestring radiation is the radiation outside (on the edge) of Earth's atmosphere. The intensity extraterestrings radiation falling on a horizontal surface at the edge of Earth's atmosphere (*Bhat*), is given by the equation:

$$H_{horiz} = H_0 \sin\alpha \qquad (6)$$

The angle of the sun's rays falling on a flat surface can be expressed by the formula (7).

$$\sin\alpha = \sin L \times \sin\delta + \cos L \times \times \cos\delta \cos\omega \qquad (7)$$

where L is the latitude, δ - declination is the angle of the Earth's axis, and ω - is the hour angle. Hour angle changes during the day with a zero when the sun is at its zenith. During the morning hour angle is negative, and in the afternoon hour angle is positive, and is calculated using the equation (8).

$$\omega = \frac{15^0}{h}\left(L_{ST} - 12h\right) \qquad (8)$$

For the calculation of hours angle used local solar time, L_{ST}, which is defined when the Sun is at the site found at its zenith. Humanity does not use local solar time, but the local time L_T, according to which the country is divided into 24 time zones. Within a single time zone, there is a unique local time, while adjacent areas differ by ± 1 h. Time zones are created in relation to the eference Greenwich longitude (longitude 0 degrees). The local longitude L_L, as compared to the calculated local time, there is the use of the equation (9):

$$L_L = \frac{15^0}{h} \Delta T_{GLT} \qquad (9)$$

In order to establish a connection between the local solar time and the location of some of the local time using the time correction factor T_C , which is calculated according to the equations (10), (11) and (12):

$$T_C = 4 \min (L - L_L) \qquad (10)$$

$$E = 9.87 \sin (2B) - 7.53 \cos (B) \sin -1.5 (B) \qquad (11)$$

$$B = \frac{360}{365}(n - 81) \qquad (12)$$

The correction factor takes into account the time difference of longitude locations L and longitude of the local L_L compared to that created time zone and the eccentricity of Earth's orbit correction using the equation of time, well, the local solar time is calculated according to the equation (13):

$$L_{ST} = L_T + \frac{T_C}{60} \qquad (13)$$

3.2.Influence of the atmosphere to solar radiation

The most common effects that occur during the passage of sunlight through the atmosphere are absorption and scattering. Since the earth is shaped balls, most of its area the light will grow at angles that are different from the normal angle of incidence. In this case, the light goes a long way through the atmosphere, which causes greater absorption and scattering of sunlight. In order to define the impact of the weakening solar radiation as it passes through the atmosphere, using the ratio of air mass AM, which is the shortest path that light travels through the atmosphere on its way to the earth's surface (*Bowden*). The coefficient of the air mass AM can be calculated according to the equation (14):

$$AM = \frac{1}{\cos L + 0.50572(96.07885 - L)^{-1.636}} \qquad (14)$$

Radiation that reaches the earth's surface is called global radiation and it can be divided into direct and diffuse radiation. The intensity of the direct component of the solar radiation I_D as a function of the coefficient of air mass AM may be determined by using the equation (15):

$$I_D = H_0\left((1 - ah) \times 0.7^{AM^{0.678}} + ah\right) \qquad (15)$$

where: *a* - constant which has an empirical value of from 0.14

h - is the altitude in kilometers.

During the sunny days of the diffuse radiation represents 10 % of the direct component and the power of global radiation IG , calculated according to the equation (16):

$$I_G = 1.1\ I_D \qquad (16)$$

Significant impact on the volume of global solar radiation on the Earth's surface and atmospheric conditions are. In the case of a clear day the bulk of the direct component of solar radiation reaches the Earth's surface, while in the case of cloudy days, sunlight cannot directly reach the Earth's surface, it comes in the form of diffuse radiation is significantly lower radiation intensity.

4. RESULTS AND DISCUSSION

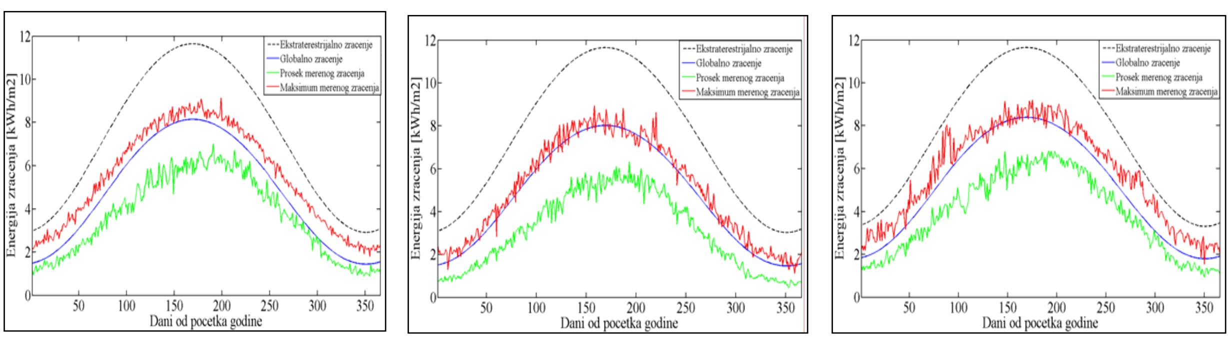
Study of the Ministry of Science and Environmental Protection shows that Serbia has an average of 280 sunny days per year, making it a highly desirable location for development and installation of solar collectors. The potential of solar energy represents 16.7 % of the total exploitable potential of renewable energy sources in Serbia. The energy potential of the solar radiation is about 30 % higher in Serbia than in Central Europe, also, the intensity of solar radiation is among the highest in Europe. Compared with Germany, Serbia has about 40 % higher average energy of solar radiation, which makes it more suitable for the construction of solar power plants. Table 1. presents the mean daily amounts of energy global solar radiation on a horizontal surface in some places in Serbia.

TABLE 1. AVERAGE DAILY CONSUMPTION OF GLOBAL SOLAR RADIATION ON A HORIZONTAL SURFACE IN SOME PLACES IN SERBIA

Place	Months of the year												Total annual	Aver. annual
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII		
Beograd	1.40	2.20	3.35	4.85	6.00	6.45	6.75	6.00	4.65	3.05	1.60	1.15	1446.80	3.96
Zrenjanin	1.30	2.15	3.45	4.90	6.05	6.35	6.55	5.90	4.45	2.95	1.45	1.05	1419.45	3.89
Kikinda	1.00	2.05	3.55	5.10	6.40	6.55	6.85	5.95	4.45	3.00	1.50	1.05	1456.50	3.99
Vršac	1.00	2.00	3.35	4.40	6.00	6.40	6.55	6.85	4.60	3.00	1.55	1.00	1424.75	3.90
Sombor	1.35	2.15	3.35	4.85	5.95	6.30	6.15	5.65	4.20	2.80	1.35	1.40	1387.35	3.80
Vrbas	1.45	2.35	3.45	4.80	5.90	6.15	6.40	5.70	4.35	2.95	1.45	1.20	1406.85	3.85
Novi Sad	1.45	2.35	3.20	4.65	5.80	6.20	6.35	5.75	4.40	2.90	1.45	1.20	1392.64	3.82
Kruševac	1.65	2.55	3.50	4.90	5.95	6.05	6.45	5.90	5.10	3.30	1.80	1.35	1519.85	4.10
Niš	1.75	2.60	3.45	5.00	6.10	6.35	6.70	6.15	5.35	3.45	1.85	1.50	1531.40	4.20
Kuršumlija	2.15	3.00	3.60	5.05	5.85	6.05	6.55	6.10	5.30	3.50	2.00	1.75	1550.50	4.25
Vranje	1.70	2.70	3.65	5.15	6.15	6.40	6.50	6.35	5.25	3.45	1.85	1.50	1543.40	4.23
K.Palanka	1.85	2.80	3.80	5.20	6.20	6.45	6.90	6.30	5.10	3.40	2.00	1.65	1567.80	4.30
Loznica	1.50	2.30	3.05	4.35	5.30	5.75	6.15	5.60	4.30	2.80	1.45	1.20	1.333.50	3.65
Kraljevo	1.60	2.50	3.35	4.95	5.90	6.20	6.60	6.05	4.65	3.05	1.65	1.35	1458.40	4.00
Kragujevac	1.50	2.40	3.35	4.80	5.85	6.10	6.45	5.90	4.85	3.30	1.70	1.30	1447.85	3.97
Smederevo	1.45	2.25	3.40	4.80	5.70	6.30	6.50	5.95	4.75	3.15	1.65	1.10	1432.75	3.93
Negotin	1.35	2.05	3.25	4.85	6.05	6.60	6.95	6.25	4.75	2.90	1.45	1.20	1453.35	3.98
Crni Vrh	1.40	2.15	3.15	4.65	5.70	6.05	6.50	5.85	4.85	3.10	1.60	1.15	1393.10	3.82
Zaječar	1.50	2.25	3.25	4.80	6.05	6.45	6.95	6.30	4.95	2.95	1.50	1.30	1498.05	4.02
Valjevo	1.45	2.25	3.10	4.40	5.35	5.95	6.35	5.75	4.45	2.95	1.50	1.20	1362.60	3.73
Zlatibor	1.50	2.30	3.10	4.35	5.10	5.65	5.90	5.35	4.30	2.75	1.60	1.30	1316.40	3.61
Priština	1.85	2.90	3.70	5.25	6.30	6.60	6.95	6.30	5.10	3.35	1.90	1.60	1578.25	4.32

The average daily global radiation energy of a flat surface during the winter period ranges from between 1.1 kWh/m^2 in the north and 1.7 kWh/m^2 in the south, and during the summer period between 5.4 kWh/m^2 in the north and 6.9 kWh/m^2 to the south. The average value of global radiation for example the territory of Germany is about 1000 kWh/m^2, while in Serbia the value of 1400 kWh/m^2. Annual ratio the actual radiation and total possible irradiation is approximately

50 %. The intensity of solar radiation is dependent both on the time of day and year, and the weather. For the design systems of the device power solar energy is essential to know the potential of solar radiation in the desired location. Testing the system unit's power with solar energy in real terms, would require a long-term measurements, and therefore developed models of the intensity of solar radiation for a given location. The data obtained from these models can be used as input parameters for the regulation of the intensity of the artificial radiation sources of radiation, i.e. solar simulators, which are used to test photovoltaic systems in different scenarios. This paper presents a model of intensity of global solar radiation on a horizontal surface. It determines the intensity of solar radiation at the desired location in the desired time without modeling the impact of weather conditions, primarily the clouds. The contribution of the work is reflected in the model that is capable of the desired location for a period of time of calculating the volume of the global solar radiation which can then be used in the actual experiments, simulations, or photovoltaic systems. The model is implemented in *Matlab* as a programming script that require users to enter latitude, longitude and altitude of the location. The model can calculate the current value of the intensity of solar radiation which is obtained by entering the value of days of the year, and local time. In addition to the current global energy intensity of solar radiation, the model is able to display daily, monthly and yearly sum of global solar radiation, which is obtained by summing up the current value with the time resolution of one minute. By entering the input data , which refer to the longitude , latitude and altitude for a given city, it is the annual chart of global solar radiation intensity displayed at in Figure 4.



a) *b)* *c)*

Figure 4: Model of global solar radiation for:a) Belgrade; b) Negotin and c) Prishtina

Data from the meteorological stations were taken from the database of the World Data Center of the radiation in St. Petersburg (*World Radiation Data Centre*). The data include information on a daily sum of global solar radiation expressed in 0.01 MJ/m^2, which are then scaled in units of kWh/m^2, which is nowadays mainly used to express the energy of solar radiation.

CONCLUSION

These data clearly show that Serbia has the resources of solar radiation well above the European average. This paper presents a model of global solar radiation intensity, which enables the determination of the intensity of global solar radiation in the desired location at a specific time during the sunny days. The resulting data can be used as input parameters in the simulation of the work photovoltaic systems. Deviation exists from the average of the measured global radiation comes from the influence of clouds, which significantly reduces the intensity of solar radiation; this effect is not treated in the model. Further study is planned to be incorporated in the model and the impact of clouds on the energy global sunlight. In the long run, the future use of solar radiation in photovoltaic technology and its integration with other branches of technology, which is consistent with the attitudes, plans and current state of the European Union and other economically leading countries of the world.

Acknowledgments: This research is conducted as a part of project no . III 43007 Global Climate Change Impact the Environment: Adaptation, Mitigation; This study is supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

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