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SEASONAL VARIATION of the SPECTRAL IRRADIANCE for the PROVINCE of MUĞLA

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Abstract

Calculation of the amount of energy from the sun as the energy source of the world is very important in terms of determining the efficiency of photovoltaic (PV) systems. At air mass zero solar spectral irradiance values have received a great deal of attention in recent years and are given in the wavelength range 0.2-4.0 μm. The amount of incoming sunlight can be calculated with different mathematical models. In this study, a mathematical modelling using SPCTRL 2 program will be discussed. The model has many variables in determining the quantity of sunlight coming in the atmosphere. With this model, the amount of solar energy falling on any on spot on the Earth's surface can be calculated and graphically modelled. In this study, direct, indirect and total (global) solar energy amounts coming from horizontal and sloping surfaces for Mugla were calculated depending on the wavelength. Horizontal and 30° inclined surfaces were calculated separately for winter, spring, summer and autumn seasons for Muğla Province. As a result, the amount of solar radiance for Muğla province was determined by mathematical modelling and the general conditions for the establishment of suitable photovoltaic system were determined.
Keywords: Solar radiation, spectral distribution, solar energy, reference modelling

MUĞLA BÖLGESİ İÇİN SPEKTRAL GÜNEŞ IŞINIMINDAKİ MEVSİMSEL DEĞİŞİM

Öz

Güneş ışınımı, yeryüzüne elektromanyetik dalgalar şeklinde gelir. Güneşten gelen enerji miktarının hesaplanması, fotovoltaik sistemlerin (PV) verimliliğinin belirlenmesi açısından çok önemlidir. Fotovoltaik sistemler (PV) güneş enerjisini elektrik enerjisine dönüştürür. Bu dönüşümde, gelen güneş ışığı miktarı matematiksel modellerle ile hesaplanabilir. Son yıllarda büyük bir ilgi gören ve 0.2-4.0 μm dalga boyunda aralığında gelen spektral ışınım değeri hava kütlesi parametresine bağlı olarak hesaplanır. Bu çalışmada SPCTRL 2 programı kullanılarak matematiksel modelleme tartışılacaktır. Model, atmosferdeki güneş ışığının miktarını belirlemede birçok değişkene sahiptir. Bu model ile herhangi bir yüzeye düşen güneş enerjisi miktarı hesaplanır ve grafiksel olarak modellenir. Çalışmamızda, Muğla ili için yatay ve eğimli yüzeylerinden gelen doğrudan, dolaylı ve toplam (küresel) güneş enerjisi miktarları dalga boyuna bağlı olarak hesaplanmıştır. Muğla ili için kış, ilkbahar, yaz ve sonbahar mevsimlerinde yatay ve 30° eğimli yüzeyler ayrı ayrı hesaplanmaktadır. Burada, yüzeydeki radyasyon miktarlarının eğim açısı ve mevsimsel değişimleri incelenmiştir. Sonuç olarak, Muğla ili için güneş ışığı miktarı matematiksel modelleme ile belirlenmiş ve uygun fotovoltaik sistemin kurulması için genel şartlar belirlenmiştir.
Anahtar Kelimeler: Güneş ışınımı, spectral dağılım, güneş enerjisi, modelleme

Cite

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1. Introduction

Sun is the world's greatest source of energy. Therefore, the sun is very important for the world. The energy released as a result of the nuclear reactions occurring on the sun spreads in different wave lengths. The radiation from the sun comes to the end of the atmosphere without any barrier to the stratum. A large amount of incoming light is in the range of 0.25 to 1.5 μm wavelength. The total amount of radiation coming to the surface has two components, directly and indirectly. Indirect radiation is due to a result of atmospheric effects, while direct radiation is the amount of radiation coming from no atmospheric effect. The amount of radiation due to atmospheric and climatic reasons is reduced. In addition, the geometric structure of the earth and the earth's movement around the sun affect the amount of incoming radiation. Calculation of the amount of energy from the sun as the energy source of the world is very important in terms of determining the efficiency of photovoltaic systems. Solar irradiance is the sun's radiant power, represented in units of W/m^2. When sunlight falls on PV diodes it is converted into electricity.

In this conversion, the amount of incoming sunlight can be calculated with a mathematical model. In this study, a software called SPCTRL 2 and a mathematical modelling developed for this program will be discussed. Direct, indirect and total (global) solar energy amounts falling on horizontal and sloping surfaces for Mugla were calculated depending on the wavelength using SPCTRL 2. Horizontal and 30° inclined surfaces were calculated separately for winter, spring, summer and autumn seasons for Muğla Province. Here, the slope angle and seasonal variation of the amounts of radiance to the surface are investigated.

2. Materials and Methods

2.1. Basic terms for solar irradiance

Just above the Earth's atmosphere The Solar Constant is the average value of solar irradiance outside the earth's atmosphere and about 1357 W/m^2 [1]. Air mass is an effect of the distribution of sunlight within the atmosphere. Air mass is calculated by,

$$\text{Air Mass (AM)} = \frac{1}{\cos(\theta)} \quad (1)$$

θ is the angle of incidence. Moreover, the amount of solar radiation in the outdoor environment varies due to the different effects in the atmosphere. Standard solar spectrum is shown in Figure 1[1].

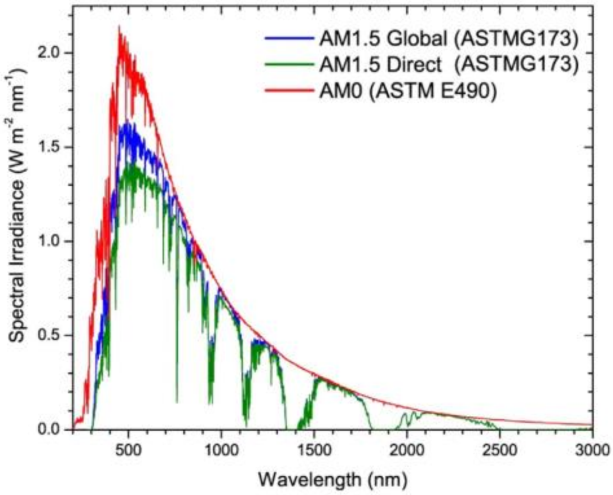

Figure 1. Standard reference solar spectrum, outside the atmosphere and at AM1.5 conditions.

The spectrum outside the atmosphere is so called air mass zero (AM0) meaning that the spectrum was measured with no air between the sun and the receiver [2,3]. The American Society for Testing and Materials (ASTM) and ASTM E490 is the standard Solar Constant and Zero Air Mass Solar Spectral Irradiance Tables where ASTMG173 spectra represent terrestrial solar spectral irradiance on a surface of specified orientation under one and only one set of specified atmospheric conditions. The split of total solar radiation on a horizontal surface into its diffuse and direct (beam) components [4]. An absolute Air Mass 1.5 (as defined in eqn.1) condition corresponds a solar zenith angle of 48.19^0. And Generally this spectrum is used for solar cell and PV module outdoor performance.

2.2. Simple Solar Spectral Model for Direct and Diffuse Irradiance on Horizontal and Tilted Planes at the Earth's Surface for Cloudless Atmospheres

The variation of the amount of total solar radiation into the atmosphere depending on the wavelength is modelled by atmospheric effects. Many researchers may obtain the capability to produce accurate terrestrial spectra using a computer program [5-7].

In this model, the direct irradiance on a surface normal to the direction of the sun at ground level for wavelength λ as;

$$\mathrm{II}_{d\lambda} = H_{0\lambda}.D.T_{r\lambda}.T_{a\lambda}.T_{w\lambda}.T_{o\lambda}.T_{u\lambda} \quad (2)$$

$H_{0\lambda}$ is the extra-terrestrial irradiance depending on wavelength λ. D is the effect of the earth-sun distance. $T_{r\lambda}$ (rayleigh scattering), $T_{a\lambda}$ (aerosol attenuation), $T_{w\lambda}$ (water vapour absorption), $T_{o\lambda}$ (ozone absorption), and $T_{u\lambda}$ (uniformly mixed gas absorption) are the transmittance functions of the atmosphere depending on wavelength [2,3,8-12].These parameters are described below.

D is given by;

$$D = 1{,}00011 + 0{,}034221.\cos(\varphi) + 0{,}00128.\sin(\varphi) + 0{,}000719.\cos(2.\varphi) + 0{,}000077.\sin(2.\varphi) \quad (3)$$

The day angle φ is given

$$\varphi = 2.\pi.\frac{d-1}{365} \quad (4)$$

where d is the day number of a year. The Rayleigh scattering parameter is given;

$$T_{r\lambda} = \exp\left\{\frac{-M'}{\lambda^4.(115{,}6406 - \frac{1{,}335}{\lambda^2})}\right\} \quad (5)$$

M' is the pressure-corrected air mass. Relative air mass as a function of solar zenith angle, Z as given by;

$$M = [cos(Z) + 0{,}15.(93{,}885 - Z)^{-1{,}253}]^{-1} \quad (6)$$

$$M' = \frac{M.P}{P_0} \tag{7}$$

where P_0 is the atmospheric pressure and equals to 1013 mb and P is the surface pressure measured. Aerosol scattering and absorption parameter is,

$$T_{a\lambda} = \exp\{-\beta_n \lambda^{-a_n} M\} \tag{8}$$

$$\alpha_1 = 1.2074 \; for \; \lambda < 0.5\mu m \tag{9}$$

$$\alpha_2 = 1.2060 \; for \; \lambda > 0.5\mu m$$

Water Vapour Absorption is,

$$T_{w\lambda} = \exp\left\{\frac{-0{,}2385.a_{w\lambda}.W.M}{(1+20{,}07.a_{w\lambda}.W.M)^{0{,}45}}\right\} \tag{10}$$

W is the precipitable water vapour (cm) in a vertical path, $\alpha_{W\lambda}$ is the water vapour absorption coefficient as a wavelength [5,7].

It is difficult to determine accurately diffuse irradiance with the simple parameterization methods that were used to calculate direct normal irradiance. In this model, different simple formulations were used for producing spectra on inclined surfaces [13-20]. After these investigations, a reasonable success was achieved and used in the SPECTRAL 2 program to calculate diffuse irradiance.

For a horizontal surface, there are three components of indirect radiation. These components are the Rayleigh scattering component ($I_{r\lambda}$), the aerosol scattering component ($I_{a\lambda}$), and the component that accounts for multiple reflection of irradiance between the ground and the air ($I_{g\lambda}$). The total scattered irradiance, $I_{s\lambda}$, is then given as,

$$I_{s\lambda} = I_{r\lambda} + I_{a\lambda} + I_{g\lambda} \tag{11}$$

In this model, Simple conversion algorithms were used to produce spectral irradiance on tilted surfaces by using the spectral direct and diffuse irradiance calculations of the previous section as inputs to the conversion algorithm. The spectral global irradiance on an inclined surface is represented as,

$$I_{T\lambda}(t) = I_{d\lambda}.\cos(\theta) + I_{s\lambda}\left[\left(\frac{I_{d\lambda}.\cos(\theta)}{H_{0\lambda}.D.\cos(Z)}\right) + 0{,}5.(1+\cos(t)).\left(\frac{1-I_{d\lambda}}{H_{0\lambda}.D}\right)\right] + 0{,}5.I_{T\lambda}.r_{g\lambda}.(1-\cos(t)) \tag{12}$$

where θ and t are the angle of incidence of the direct beam on the tilted surface and the tilt angle of the inclined surface, respectively. The tilt angle is zero for a horizontal surface and is 90° for a vertical surface. The spectral global irradiance on a horizontal surface is represented as,

$$I_{T\lambda} = I_{d\lambda}.\cos(Z) + I_{S\lambda} \tag{13}$$

Spectral irradiance is calculated for horizontal and different tilt angles with SPECTRAL 2 where it is a simple software that calculates Solar Spectral Distribution for Direct and Diffuse Irradiance on horizontal and tilted planes at the earths' surfaces for cloudless atmospheres. Calculations were made for the Muğla province and one month was chosen to represent every season. In addition, the days represented in the calculations were selected for each month and for the representative days of the month. The fixed values used in calculations are given in Table 1.

Table 1. Some parameters for calculations for Muğla

Latitude	37^0 N
Longitude	28^0 E
Pressure	930 mb
Altitude	660m

3. Results and Discussion

In photovoltaic applications PV planes are installed mostly with latitude tilts or obeying the roof slopes. In Muğla province generally 30^0 tilt roof are constructed so in the present study solar spectral distribution. So, irradiation distribution on 30^0 tilt sloping surfaces for Muğla province is calculated and graphically modeled by using mathematical model mentioned in previous section. SPCTRL2 uses all mathematical equations for calculating the amount of radiation coming to a horizontal and 30^0 sloping surface. For an annual basis Muğla has solar energy exceeding 1650 kWh/m² on a horizontal surface which is the total area under the spectral irradiance-wavelength curves. PV modules are tested at Standard Test Conditions (STC) which uses solar irradiance distribution at autumn, solar cell operating cell temperature at winter and solar irradiance at summer. But under operating these all factors never come together. So calculating the PV performance one of the methods is using the annual real output values of the PV system. Materials used in solar cells are very important in converting the solar irradiance to electricity and materials spectral response due to wavelength is very important at this point [1]. There are several PV systems installed in Muğla province (exceeding 20MWp installed power) and most them are crystalline silicon based solar cells which responses the wavelength under 1.1 or 1.2 μm. Although maximum spectral irradiance occurs about 0.45μm at global standard measurements, at this point power per area changes during a year. This variation is generally analyzed dividing a year in seasons. In this study, February is selected for winter season, April for spring, July for summer and November for autumn. As expected the power of the irradiance per square meter decreases in winter season and maximum spectral irradiance occurs about 0.45μm but the solar irradiance is about 250 W/m²/ μm (Fig.2).

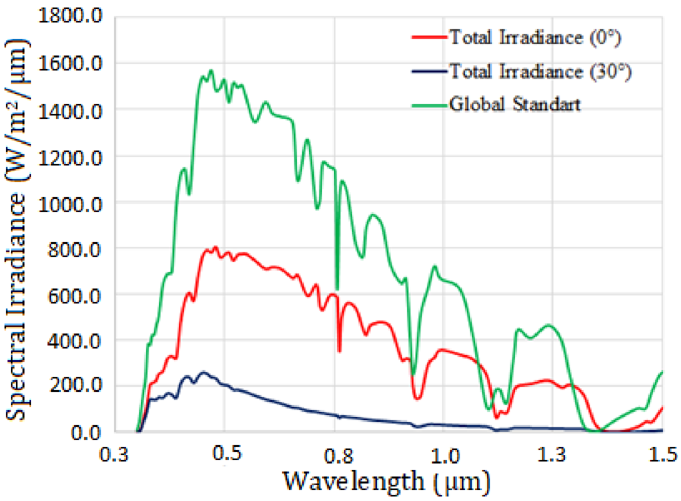

Figure 2. Spectral irradiance versus wavelength for month of January.

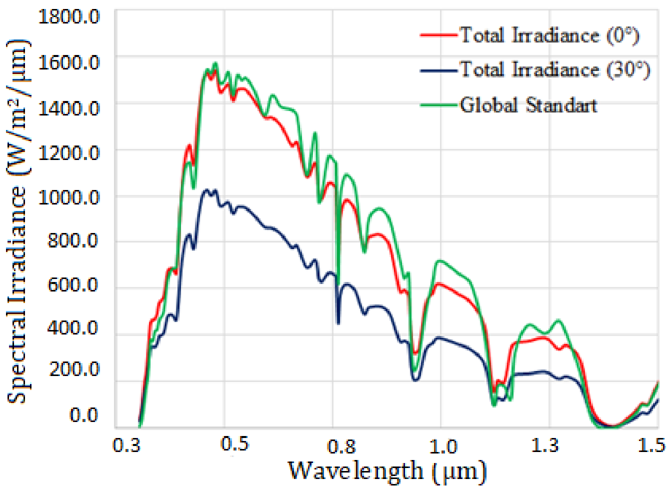

Figure 3. Spectral irradiance versus wavelength for month of April

Maximum total irradiance in a clear sky day at noon time is measured about 800W/m^2 in winter but mean irradiance at 30^0 tilted surface is about 300W/m^2.

In spring, summer and fall seasons maximum spectral irradiance occurs about 0.45μm but the solar irradiance is about 1000 W/m^2/ μm (Fig.3) and sometimes higher than 1200 W/m^2/ μm (Fig.4) for tilted surfaces. In fall season maximum spectral irradiance occurs below 0.45μm (Fig.5). Sometimes in late November there are several clear sky days at Muğla and total solar irradiance values at tilted surfaces exceeds 800 W/m^2 although the mean is below 400 W/m^2.

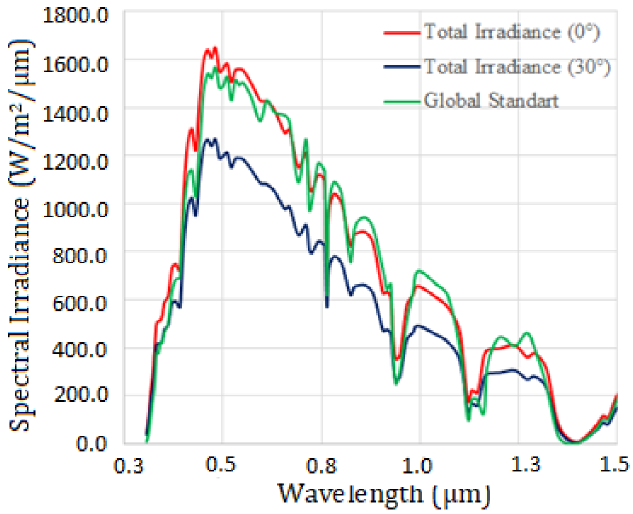

Figure 4. Spectral irradiance versus wavelength for month of July

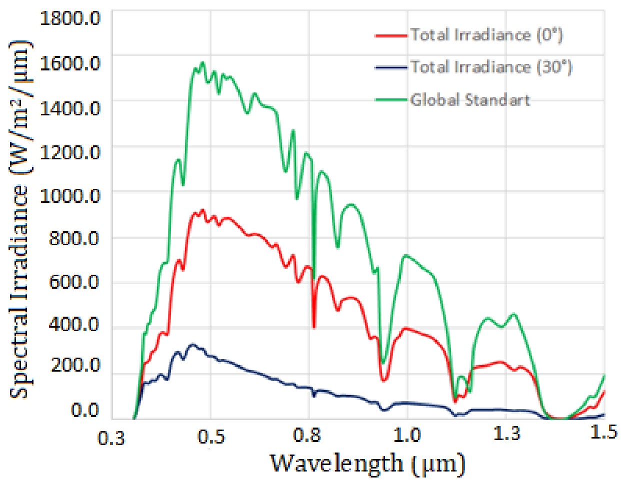

Figure 5. Spectral irradiance versus wavelength for month of November

The amount of incoming radiation varies due to atmospheric and geographical reasons as given in Figures 2-5. It is obvious that in spring and summer maximum of solar spectrum shifts to higher wavelengths this is known as red-shift and in fall and winter maximum of solar spectrum shifts to lower wavelengths this is known as blue-shift. In fact this shift is caused from the distance between sun-earth and this phenomena is explained with Doppler effect.

4. Conclusion

With the developed model, the amount of solar radiation in the atmosphere can be calculated for any degree of the solar rays and any moment of the day with local time. At this point, more obvious results are obtained about the efficiency of the photovoltaic systems. In the calculations made for the Mugla province, the amount of radiation coming to the horizontal surface in summer and spring seasons and the radiation amount to the inclined surface are about the same value but the amount of radiation coming to the sloping surface in winter and autumn is more than the amount of radiation coming to the horizontal surface. As a result, more energy conversion can be achieved from sloping surfaces in winter and autumn. One of the reasons why more radiation comes to the sloping surfaces in the winter and autumn is the distance and angle between the sun and the earth.

Using the SPCTRL 2 program, we can calculate the amount of radiation to the surface of the slope and the slope of 30° for the Mugla province depending on the atmospheric and geographical effects as seen from Figures 2-5. The amount of radiation from any surface can also be calculated for a different region or area.

5. Conclusion

Some part of this work is presented at IMSMATEC 2018 and that work has been revised and expanded in the present study.

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