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An Empirical Technique for Estimating Solar Radiation on Earth Surface in India

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Abstract—This paper describes the empirical technique for estimating the solar radiations which includes the mentioned parameters (H_{ga}), (H_{oa}) at the given location. Calculation suggests the proper estimation of monthly averaged global solar radiation on earth surface which make more efficient utilization of solar power. The technique gives the effective use of solar radiation for solar power generation at different months and at different places of India

Keywords—Solar radiation, Sunrise, Sunset, Day length Declination angle, solar radiation spectrum, Solar irradiation under different Air mass, Solar Constant

I. INTRODUCTION

There are many conventional energy sources that are available to us like oil, natural gas and coal to meet our various energy demands. However these sources are extremely limited in supply and it is estimated that these sources can meet our energy demands for another fifty to seventy years only. Therefore scientists all over the world are focusing their attention on renewable energy resources as a solution to the forthcoming energy crises. India is rich in natural and renewable energy resources and that these sources can supplement the existing energy supplies but cannot substitute the conventional energy supplies. Renewable energy potential in India has not been fully assessed or adequately tapped, while the India's fossil fuel resources are limited compared to global reserves. Renewable sources of energy offer the most potential energy conversion and development option for future. Renewable energy sources consist of wind, solar, hydro, geothermal, ocean and biomass etc. The most common advantage of each is that they are renewable and everlasting. Most of them are clean energy sources, as they don't pollute air and they don't contribute to global warming or greenhouse effects. Since these sources are natural, the operating cost is also low. A common disadvantage to all is that it is difficult to produce large quantities of electricity from them since most of them are dilute and intermittent in nature. Since new technologies are needed to harness them, the cost of initiating the new power plants is high.[1]

The obvious choice of a clean energy source, which is abundant and could provide security for the future development and growth, is solar energy. A part from sunlight and solar heating, energy of the sun is also available to us indirectly in the form of biomass, wind energy and hydroelectric energy, and has many advantages over the conventional energy sources. In this paper, a mathematical model is developed to simulate the availability of solar radiation in India.

II. SOLAR ENERGY: ADVANTAGES

It is an everlasting, renewable energy source. It is clean energy source, no potential damage to the environment. It is a very large source of energy. The power from the sun intercepted by earth is about 1.8 x 10^{11} MW, which is many thousand times larger than our current power consumption from all sources.

Additionally, solar energy is free, does not cause pollution and is available to all unlike fossil fuel sources, which are concentrated at some locations only. This fact provides a chance that individual can generate his own energy depending on the requirement, at his place of choice. This equitable availability can also play a role in social development, especially for developing countries such as India.
The modular character of technology allows gradual implementation and is easier to finance.[2]

III. SOLAR ENERGY

While fossil fuels will be the main fuels for thermal power, there is a fear that they will get exhausted eventually in the next century. Therefore other systems based on non-conventional and renewable sources are being tried by many countries. These are solar, wind, sea, geothermal and biomass. Solar energy can be a major source of power. Its potential is 178 billion MW which is about 20,000 times the world's demand. But so far it could not be developed on a large scale. Sun's energy can be utilized as thermal and photovoltaics. The former is currently being used for steam and hot water production. Solar energy has the greatest potential of all the sources of renewable energy and if only a small amount of this form of energy could be used, it will be one of the most important supplies of energy specially when other sources in the country have depleted. Energy comes to the earth from the sun. This energy keeps the temperature of the earth above that in colder space, causes current in the atmosphere and in ocean, causes the water cycle and generate photosynthesis in plants. The solar power where sun hits atmosphere is 10^{17} watts, whereas the solar power on earth's surface is 10^{16} watts. The total world-wide power demand of all needs of civilization is 10^{13} watts. Therefore, the sun gives us 1000 times more power than we need. If we can use 5% of this energy, it will be 50 times what the world will require.

Attempts have been made to make use of this energy in raising steam which may be used in driving the prime movers for the purpose of generation of electrical energy. However on account of large space required, uncertainty of availability of energy at constant rate, due to clouds, winds, haze etc., there is limited application of this source in the generation of electric power.[2]

IV. ELECTRICITY FROM SOLAR ENERGY

Electricity can be produced from the solar energy by photo voltaic solar cells, which convert the solar energy directly to electricity. The most significant applications of photo voltaic cell in India are the energisation of pump sets for irrigation, drinking water supply and rural electrification covering street lights, community TV sets, medical refrigerators and other small power loads. Electricity is directly generated by utilizing solar energy by the photo voltaic process. When photons from the sun are absorbed in a semi- conductor, they created free electrons with higher energies than the electrons which provide the bonding in the base crystal. Once these free electrons are created, there must be an electric field to induce these higher energy electrons to flow out of the semiconductor to do useful work. The electric field in most solar cells is provided by a junction of materials which have different electrical properties. The photovoltaic effect can be described easily for P-N junction in semi-conductor materials of solar cells which are silicon, cadmium, sulphide / copper sulphide, Gallium Arsenide etc.[2]

V. SOLAR SPECTRUM AT THE EARTH'S SURFACE

Earth continuously receives about 174 X 10^{15}W of incoming solar irradiation at the upper atmosphere. When it meets the atmosphere, 6 percent of the irradiation is reflected and 16 percent is absorbed. The sun rays outside the earth's atmosphere travels parallel to each other. When the solar radiation passes through the earth atmosphere it undergoes several interactions (absorption and scattering) with the gaseous molecules (CO2, Ozone, water vapours etc.) and other particles in the atmosphere. The interaction of solar radiation with Earth's atmosphere is shown in Figure 1.

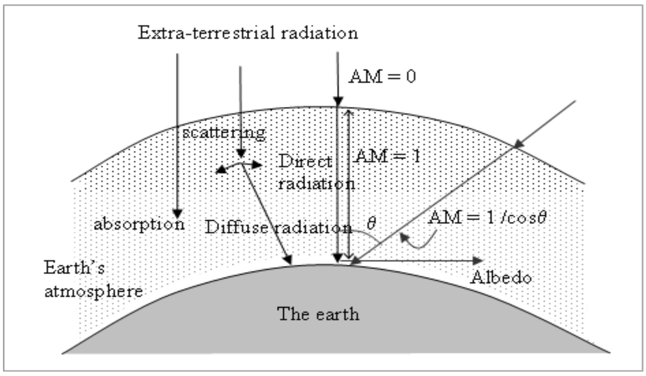

Figure 1. Interaction of solar radiation in earth's atmosphere (am- air mass)

In the absorption interaction, the energy of the solar radiation is given to the gaseous molecules and other particles in the atmosphere. Thus, it is a loss of radiation. Typically, about 16 % of the radiation gets absorbed in the atmosphere while passing through it. Due to scattering interaction, the direction of sun rays changes. This results in redistribution of scattered radiation randomly in all directions. The scattered radiation is called diffuse radiation. The radiation which does not go through either absorption interaction or scattering interaction, but reaches the earth surface directly is known as direct radiation or beam radiation. Once the radiation reaches the Earth's surface some of it (diffuse and direct as well) get reflected by the ground and other objects on the ground. This reflected component is called as albedo radiation. Thus, the total radiation reaching a given point on the earth surface is sum of diffuse radiation, direct radiation and albedo radiation. This sum is know as global radiation. On a normal sunny day, the diffuse radiation is about 15 to 20 percent of that of direct solar radiation. On cloudy days, diffuse radiation depends on type of clouds, and it could be very large fraction of the global radiation. The amount of albedo radiation generally depends on the nature of the surface coverage; whether there is water, snow, tall buildings, etc.

The solar radiation spectrum that reaches the earth's surface is shown in figure **2.** On comparison with extra-terrestrial radiation spectrum, one can notice that the peak irradiance is reduced to about 1600 W/m^2 –nm from an extra-terrestrial irradiance value of over 2000 W/m^2 –nm. This happens due to the absorption and reflection losses in the earth's atmosphere.

The solar radiation spectrum that reaches the earth's surface is shown in figure **2.** mainly consists of visible and infrared radiation.[3]

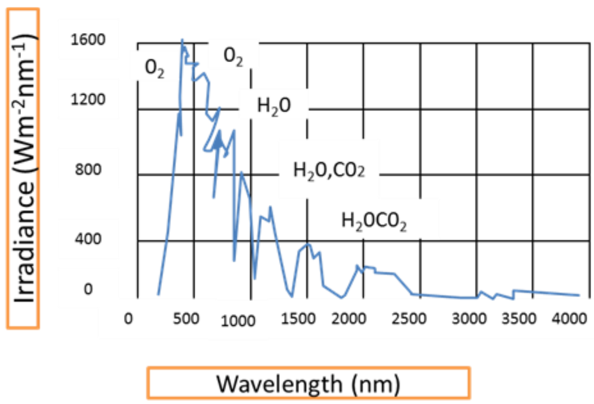

Figure 2. Solar radiation spectrum at the earth's surface.

The UV component in the spectrum is small. The distribution of solar spectrum on the earth's surface is given in Table 1.

Table 1. Solar spectrum on the earth's surface

Type of radiation	Range of wavelengths (nm)	% of energy carried
Ultraviolet Radiation	150 to 380	7.6
Visible radiation	380 to 720	48.4
Infrared radiation	720 to 4000	43
Other radiation	>4000	1

VI. AIR MASS

Spectrum with irradiation of 1000 W/m^2. When solar radiation travels through earth's atmosphere or the air mass (AM), the amount of sunlight scattered or absorbed depends on the length of the path of the rays. Less solar radiation will reach to the surface if rays have to travel longer distance though the air mass. This can be noticed during the morning and evening times when the solar irradiation is less than the noon. Radiation spectrum just outside the earth's atmosphere is referred as AM0 spectrum (the number with 'AM' refers to the distance travelled by sunrays in the earth's atmosphere). When sun is at the overhead position, during noon, radiation travels a minimum distance through air mass before reaching the surface. In this condition the spectrum reaching earth's surface is known as AM1 When the sun is at a position other than the overhead position, rays will have to travel longer distance in the air mass (as compared to overhead position of AM1) to reach the surface. If the sunrays are making an angle θ with the vertical at a given point on the earth's surface, then AM that the sunrays have to travel is given by the following equation:

$$AM = \frac{1}{\cos\theta} \tag{1}$$

Solar irradiation reaching the surface under different air mass conditions are summarized in table 2**.** Not only the irradiation, but the spectral contents also depend on the air mass. Therefore, for characterisation of solar cells irradiation as well as spectrum is defined. It is a worldwide standard to test solar cells under AM 1.5 global solar

Table 2. Solar irradiation reaching the surface under different air mass conditions

Air mass	Solar irradiation Reaching the surface (W/m2)
AM0(extra terrestrial)	1376
AM1(sun at overhead position)	1105
AM1.5 (sun at about 48 degree from overhead position)	1000
AM2 (sun at about 60 degree from overhead position)	894

Inclination of the axis can take several values. In particular case where ψ = Ø, meaning surface is inclined at an angle equal to the local latitude of the location. This rotation scheme is known as polar tracking, as the collector rotation axis and axis around which the earth rotates becomes same. In this case,

$$\cos\theta = \cos\delta \text{ and } \cos\beta = \cos\omega\cos\phi \quad (2)$$

From Equation 2 It can see that for polar axis tracking with constant speed of rotation θ = δ, i.e., angle of incidence depends only on declination angle. Thus, collector rotation speed is equal to earth's rotation speed, collector's perpendicular will always be in the plane of line joining the sun-earth and its projection on horizontal plane (but not exactly perpendicular).

VII. DECLINATION ANGLE δ

The declination angle is defined as the angle between the lines joining the centre of the earth to the centre of the sun with its projection on the equatorial plane of the earth. The declination angle is graphically shown in figure 4. The variation in declination angle is due to the inclination of the earth's polar axis and its revolution around the sun. Declination angle varies between -23.45^0 (December solstice) to +23.45^0 (June solstice). Twice in the year the value of declination angle becomes zero, on two equinoxes (in March and September) as shown in Figure 3.

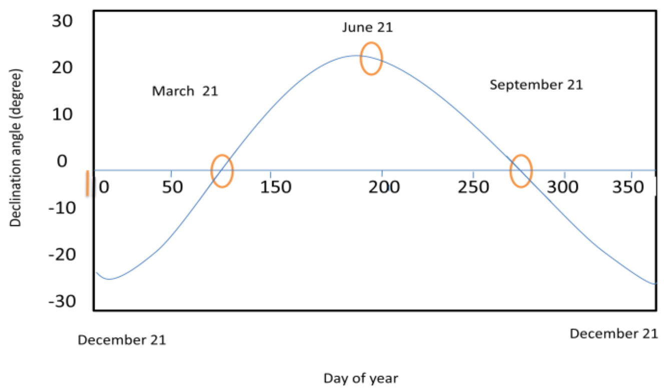

Figure 3. The declination angle is shown graphically

Value of declination angle remains positive when large area of the northern hemisphere is illuminated than the southern hemisphere. It becomes negative when the opposite happens. Declination angle in degrees can be mathematically presented by the following equation:

$$\delta = 23.34\sin\left(\frac{360}{365}(284+n)\right) \quad (3)$$

Here n is the *n*th day of the year starting from January, i.e., *n* = 1 for January 1st. The value of δ represents different times of a year, due to which it is an important parameter in the estimation of the amount of solar radiation falling on a given location at a given time of the year. Also, it is the change in the declination angle, due to which the sun's position to an observer at a fixed location appears to be different in winter and in summer.

VIII. SOLAR CONSTANT (S)

Solar constant denoted by S is the energy from sun per unit time received on a unit surface area perpendicular to the direction of propagation of radiation at earth mean distance from sun outside the atmosphere. S value according to NASA/ASTM is 1353 watt per square meter. Average solar radiation outside the earth atmosphere is known as solar constant. [4] Actual radiation can be estimated with following eq..

$$S_t = S\left(1 + 0.033 \cos\left\{\frac{360n}{365}\right\}\right) \tag{4}$$

Where n is n^{th} the day of the year

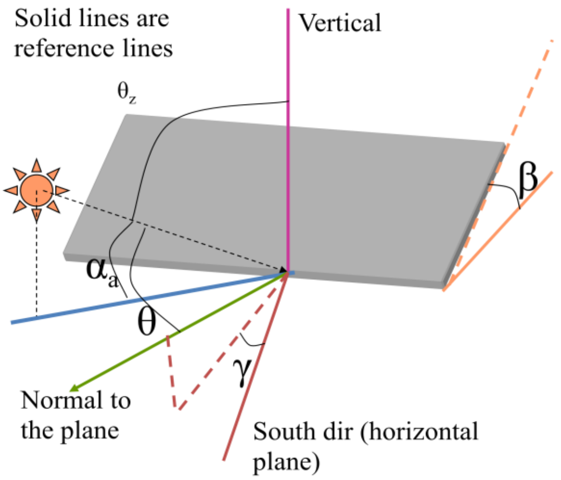

Figure 4. Solar radiation geometry.

Figure 4. represents the angles to describe the position of the sun in the sky. Angles are described in the following ways:

A. Zenith Angle- It is vertical angle between the sun rays and a line perpendicular to the horizontal plane through the point i.e. the angle between the beam from the sun and the vertical.

B. Solar Azimuth Angle(γ): angle between surface normal and south direction in horizontal plane, (+180^o to -180^o, Positive in the east of south)

C. Latitude (Φ): Latitude is the angular distance of the point on earth measured north or south of the equator is latitude.($-90<\Phi<90$)

D. Longitude: Angular distance measured east and west of prime meridian is longitude

E. Hour angle (w)– angular measure of time w.r.t. noon (LAT), 15^o per hour, (+180^o to -180^o, Positive in the morning)

IX. SUNRISE, SUNSET AND DAY LENGTH

Incidence angle of sunrays on a horizontal plane. This equation can be used to find out the Sunrise and sunset time, which normally are presented in sunrise and sunset hour angle ωs. Due to the symmetry, the value of sunrise and sunset hour angle will be the same.. When the collector surface is lying flat on the ground, its angle with horizontal plane will be zero, i.e. β=0°. Thus for the horizontal surface,

$\cos\theta = \sin\phi\,(\sin\delta\cos\beta + \cos\delta\,\cos\gamma\,\cos\omega\,\sin\beta) + \cos\phi\,(\cos\delta\,\cos\omega\,\cos\beta - \sin\delta\,\cos\gamma\,\sin\beta) + \cos\delta\,\sin\gamma\,\sin\omega\,\sin\beta$ **(5)**

$$\cos\theta = \sin\varphi\sin\delta + \cos\varphi\cos\delta\cos\omega = \cos\theta \quad \textbf{(6)}$$

The sunrise and sunset hour angle will be the anglefor which the incidence angle of sunrays is 0° or zenith angle is 90°. Substituting ϕ= 0° in eq.5

$$\cos\omega_s = -\tan\phi\tan\delta \quad \textbf{(7)}$$

$$\omega_s = \cos^{-1}(-\tan\phi\tan\delta) \quad \textbf{(8)}$$

Above equation 7 will give a positive and a negative value of the hour angle. The hour angle is considered positive before noon and negative after noon. The positive value of ω_s will be corresponding to sunrise hour angle ω_{st} and the negative value of ω_s will be corresponding to the sunset hour angle ω_{ss}. The sunrise and sunset hour angles can beconverted into hours, by using 1 hour = 15^0.

The day length is duration from the sunrise hour angle to the sunset hour angle. Due to symmetry both angles are same for the horizontal collector. Thus, the day length will be equal to $2\omega_s$. In terms of the number of hours the day length S_{max} (day length or maximum number of sunshine hours) will be given as:

$$S_{\max} = \frac{2}{15}\cos^{-1}(-\tan\phi\tan\delta) \quad \textbf{(9)}$$

If the collector surface is inclined and south facing the sunrise and sunset hour angle.

$$\omega_{st} = \cos^{-1}\{-\tan(\phi-\beta)\tan\delta\} \quad \textbf{(10)}$$

For inclined surface the sunrise and sunset hour angles will be smaller, which means that day length for inclined collector surfaces will be smaller than horizontal surface.[3] If the collector surface is inclined but does not have exactly south facing surface then eq. 5 can be used to find out the sunrise and sunset hour angles. In this case the magnitude of sunrise and sunset hour angle will not be the same.

X. ESTIMATION OF AVERAGE SOLAR RADIATION

Calculate the amount of solar radiation falling on a collector at a given time and location, the direct or beam radiation and diffuse radiation should be either measured or estimated using empirical equations. Due to economic reason, it is not possible to measure the solar radiation for all locations. Therefore, often it is required to estimate the direct, diffuse and global radiation from the empirical relations. Though the relationships are not completely empirical, they use the parameters that are based on measured meteorological data. The parameters such as sunshine hours, sky clearness index etc. are used.

The monthly average daily global radiation on a horizontal surface H_{ga} is given by the following equation

$$\frac{H_{ga}}{H_{oa}} = a + b\left(\frac{Sa}{S_{max}a}\right) \quad (11)$$

Where H_{0a} is a monthly average extra–terrestrial solar radiation at horizontal surface [at top of the atmosphere] and S_a and S_{max} are the monthly average daily sunshine hours and maximum possible daily sunshine hours (the day length) at a given location. Here *a* and *b* are constants.

Where a & b are the values of constants used in for estimation of monthly averaged global solar radiation. The values of constants *a* and*b* are used for estimation of monthly averaged global solar radiations. In Eq.11 one needs to have a value of H_{0a} which can be estimated from the instantaneous value of extra-terrestrial solar radiation.[3] Integration of extra-terrestrial radiation over a day will be daily value of extra-terrestrial solar radiation, H_0 (H_{0a} if it is estimated for a given day of month) which can be written as:

$$H_0 = St\int \cos\theta dt \tag{12}$$

$$= S\left(1+0.033\cos\frac{360n}{365}\right)\int_{Sunrise}^{sunset} \sin\emptyset\sin\delta + \cos\emptyset\cos\delta\cos\omega\, dt \tag{13}$$

Here *t* is time in hours. It can be converted to time in angles ω (radians) as:

$$dt = \frac{180}{15\pi}\times d\omega \tag{14}$$

$$H_0 = \frac{12}{\pi}S\left(1+0.033\cos\frac{360n}{365}\right)\int_{-ws}^{ws} \sin\emptyset\sin\delta + \cos\emptyset\cos\delta\cos\omega\, d\omega \tag{15}$$

The integration of Eq.15 will give the following

$$H_0 = \frac{24}{\pi}S\left(1+0.033\cos\frac{360n}{365}\right)\omega_s\sin\emptyset\sin\delta + \cos\emptyset\cos\delta\sin\omega_s \tag{16}$$

If *S* is in W/m^2, H_0 will be in W-h/m^2.

XI. ESTIMATED SOLAR RADIATION DATA FOR VARIOUS CITIES OF INDIA. ALL RADIATION DATA ARE GIVEN IN TERMS OF KWH/M^2 /MONTH

City – Nagpur

a = 0.27 , *b* = 0.50, Latitude: 21.15, Ground reflectivity = 0.2

Table 4. All radiation data for Nagpur

Month	H_0	K_t	S	S_{max}	H_g	Beta=Latitude		Beta=Latitude +15		Beta = Latitude -15	
						Rb	H_{total} Tilted Surface	Rb	H_{total} Tilted Surface	Rb	H_{total} Tilted surface
Jan	7.08	0.69	9.30	10.87	4.94	1.36	6.31	1.51	6.87	1.12	5.41
Feb	8.20	0.70	9.90	11.32	5.80	1.24	6.88	1.30	7.18	1.08	6.18
Mar	9.48	0.65	9.20	11.88	6.23	1.10	6.65	1.08	6.53	1.04	6.43

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Apr	10.59	0.64	9.50	12.49	6.89	0.97	6.72	0.87	6.19	1.01	6.91
May	11.21	0.63	9.70	13.01	7.21	0.87	6.56	0.71	5.71	0.98	7.09
Jun	11.40	0.50	6.30	13.27	5.78	0.67	4.85	0.84	5.16	0.97	5.69
July	11.33	0.40	3.50	13.15	4.57	0.70	4.11	0.86	4.15	0.97	4.52
Aug	10.89	0.41	3.60	12.71	4.48	0.81	4.16	0.93	4.17	0.99	4.47
Sep	9.96	0.49	5.60	12.11	4.99	1.00	4.92	1.05	4.92	1.03	5.05
Oct	8.64	0.63	8.60	11.50	5.56	1.19	6.26	1.23	6.36	1.07	5.83
Nov	7.38	0.69	9.50	10.98	5.18	1.33	6.51	1.45	7.01	1.11	5.63
Dec	6.77	0.69	9.20	10.74	4.73	1.40	6.19	1.57	6.81	1.13	5.22

City – Delhi

a = 0.25, *b* = 0.57, Latitude: 28.58, Ground reflectivity = 0.2

Table 5. All radiation data for Delhi

Month	H_0	K_t	S	S_{max}	H_g	Beta=Latitue		Beta=Latitude+15		Beta=Latitude -15	
						Rb	H_{total} Tilted Surface	Rb	H_{total} Tilted surface	Rb	H_{total} Tilted surface
Jan	5.95	0.66	7.70	10.40	4.00	1.60	5.72	1.77	6.20	1.33	4.95
Feb	7.25	0.68	8.70	11.04	5.07	1.39	6.60	1.47	6.88	1.22	5.95
Mar	8.83	0.63	8.00	11.82	5.62	1.18	6.25	1.16	6.11	1.12	6.06
Apr	10.36	0.63	8.80	12.69	6.69	0.99	6.59	0.89	6.05	1.03	6.80
May	11.36	0.60	8.30	13.42	6.84	0.86	6.16	0.69	5.38	0.96	6.66
Jun	11.74	0.52	6.10	13.79	5.89	0.65	4.85	0.81	5.12	0.94	5.70
July	11.58	0.50	5.70	13.63	5.66	0.68	4.77	0.84	4.97	0.95	5.51
Aug	10.82	0.52	6.00	13.00	5.55	0.82	4.97	0.94	5.13	1.00	5.53
Sep	9.42	0.59	7.30	12.16	5.60	1.05	5.69	1.10	5.78	1.08	5.86
Oct	7.77	0.69	9.10	11.30	5.51	1.32	6.90	1.36	7.08	1.19	6.34
Nov	6.29	0.72	9.20	10.57	4.69	1.54	6.89	1.68	7.47	1.30	5.90
Dec	5.60	0.69	8.00	10.21	3.90	1.67	5.91	1.87	6.49	1.36	4.98

City – Vishakapatnam

a = 0.28, *b* = 0.47, Latitude: 17.72, Ground reflectivity = 0.2

Table 6. Solar radiation data for Vishakhapatnam

Month	H_0	K_t	S	S_{max}	H_g	Beta=Latitue		Beta=Latitude+15		Beta=Latitude -15	
						Rb	H_{total} Tilted Surface	Rb	H_{total} Tilted surface	Rb	H_{total} Tilted surface
Jan	7.58	0.69	9.50	11.06	5.18	1.28	6.23	1.42	6.78	1.05	5.37
Feb	8.60	0.69	10.10	11.44	5.98	1.18	6.80	1.25	7.09	1.03	6.13
Mar	9.73	0.64	9.00	11.90	6.18	1.07	6.46	1.05	6.34	1.02	6.26
Apr	10.64	0.63	9.20	12.40	6.69	0.97	6.52	0.87	6.02	1.00	6.69
May	11.08	0.62	9.10	12.83	6.80	0.89	6.29	0.72	5.53	0.99	6.75
Jun	11.19	0.47	5.00	13.04	5.15	0.68	4.49	0.85	4.69	0.98	5.11
July	11.16	0.43	3.90	12.95	4.70	0.71	4.23	0.87	4.33	0.99	4.68
Aug	10.87	0.48	5.30	12.58	5.19	0.81	4.75	0.93	4.89	1.00	5.18
Sep	10.13	0.52	5.90	12.09	5.16	0.98	5.07	1.03	5.09	1.01	5.18
Oct	8.99	0.59	7.60	11.59	5.29	1.14	5.71	1.18	5.76	1.03	5.38
Nov	7.85	0.65	8.60	11.16	5.04	1.25	5.89	1.37	6.26	1.05	5.20
Dec	7.29	0.67	8.90	10.96	4.8	1.31	5.87	1.47	6.40	1.05	5.01

City – Srinagar

a = 0.35, *b* = 0.40, Latitude: 34.08, Ground reflectivity = 0.2

Table 7. Solar radiation data for Srinagar

Month	H_0	K_t	S	S_{max}	H_g	Beta=Latitue		Beta=Latitude+15		Beta=Latitude -15	
						Rb	H_{total} Tilted Surface	Rb	H_{total} Tilted surface	Rb	H_{total} Tilted surface
Jan	5.07	0.44	2.40	10.00	2.26	1.86	2.75	2.04	2.90	1.55	2.66
Feb	6.47	0.49	3.80	10.81	3.17	1.55	3.81	1.63	3.81	1.37	3.63
Mar	8.26	0.51	4.70	11.78	4.21	1.26	4.58	1.24	*4.42*	1.20	4.55
Apr	10.08	0.54	6.00	12.86	5.41	1.01	5.31	0.91	4.88	1.05	5.51
May	11.37	0.58	7.60	13.77	6.49	0.85	5.80	0.68	5.06	0.96	6.29
Jun	11.89	0.60	8.60	14.23	7.03	0.64	5.41	0.80	5.96	0.93	6.68
July	11.67	0.59	8.10	14.03	6.78	0.67	5.38	0.83	5.86	0.94	6.51
Aug	10.66	0.60	7.80	13.24	6.24	0.83	5.50	0.95	5.83	1.01	6.26
Sep	9.00	0.62	7.80	12.20	5.45	1.10	5.70	1.16	5.81	1.14	5.89
Oct	7.05	0.64	7.60	11.12	4.40	1.45	5.62	1.49	5.68	1.31	5.25
Nov	5.43	0.63	6.60	10.21	3.30	1.77	4.83	1.93	5.10	1.50	4.30
Dec	4.69	0.51	3.80	9.77	2.37	1.96	3.32	2.18	3.48	1.61	2.99

XII. CONCLUSION

This paper gives exact solution for determining the empirical technique for estimating the solar radiation energy which includes monthly averaged daily global radiation on a horizontal surface (Hga), monthly averaged extra terrestrial solar radiation at horizontal surface (Hoa)(at the top of atmosphere), and monthly averaged daily sunshine hours and maximum possible daily sunshine hours(day length) at a given location

With the help of this technique, the solar radiations required to generate solar power at different places months and at different places of India can be estimated.

NOMENCLATURE:

θ- Incidence angle of the sunrays of collector

θ_z- Zenith angle

δ - Declination angle

β - Tilt of collector with respect to horizontal plane

γ - Orientation of the collector

φ- Latitude of Location

n- Day of a Year

ω_s- Sunrise hour angle for horizontal collector

ω_{st}- Sunrise hour angle for tilted collector

a,b – Constants (depend on location)

Kt – Clearness index

S – Solar constant

S*a* – Actual number of sunshine hours per day at a given location

S_{max} – Maximum number of sunshine hours per day at a given location or day length

H_{ga} – Monthly averaged daily global solar radiation on a horizontal plane

H_{oa} – Monthly averaged daily extra – terrestrial solar radiation for a given location

R_b- Tilt factor for beam radiation

ρ – Reflectivity of the ground

H_T- Monthly averaged daily total radiation on tilted surface

H_g – Monthly averaged daily global radiation on tilted surface

H_d – Monthly averaged daily diffuse radiation

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