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Calculation of Irradiance and Tilt angle of Solar Panel for a Particular Geographical Location

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Abstract:
Solar energy is one of the freely available renewable sources of energy and abundant in almost every part of the world. It is the most fundamental among the alternative sources of energy. With a view to collect Maximum energy from sun it is necessary to calculate the Solar Irradiance and Tilt angle of Solar Panel. In this paper, an attempt has been taken to track the exact location for particular geographical location. Microsoft excel have been used to Calculate Solar Irradiance and the tilt angle of solar panel. Here, the location of Dombivli in the state Maharashtra, India has been considered.

Keywords: Solar energy, Local solar time, Local Standard Time Meridian, Elevation, EoT, Azimuth, Time correction factor, Declination, Hour angle, Solar Irradiance, Tilt angle, Latitude, Solar Photovoltaics.

I. INTRODUCTION

Solar energy in one form or another is the source of nearly all energy on the earth. Humans, like all other animals and plants, rely on the sun for warmth and food. However, people also harness the sun's energy in many other different ways. For example, fossil fuels, plant matter from a past geological age, is used for transportation and electricity generation and is essentially just stored solar energy from millions of years ago. Similarly, biomass converts the sun's energy into a fuel, which can then be used for heat, transport or electricity. Wind energy, used for hundreds of years to provide mechanical energy or for transportation, uses air currents that are created by solar heated air and the rotation of the earth. Today wind turbines convert wind power into electricity as well as its traditional uses. Even hydroelectricity is derived from the sun. Hydropower depends on the evaporation of water by the sun, and its subsequent return to the Earth as rain to provide water in dams. Photovoltaics (often abbreviated as PV) is a simple and elegant method of harnessing the sun's energy. PV devices (solar cells) are unique in that they directly convert the incident solar radiation into electricity, with no noise, pollution or moving parts, making them robust, reliable and long lasting. [2]

II. BASIC OF SUN'S POSITION

The azimuth angle and the elevation angle at solar noon are the two key angles which are used to orient photovoltaic modules. However, to calculate the sun's position throughout the day, both the elevation angle and the azimuth angle must be calculated throughout the day. These angles are calculated using "solar time". In conventional time keeping, regions of the Earth are divided into certain time zones. However, in these time zones, noon does not necessarily correspond to the time when the sun is highest in the sky. Similarly, sun rise is defined as the stage when the sun rises in one part of the time zone. However, due to the distance covered in a single time zone, the time at which the sun actually clears the horizon in one part of the time zone may be quite different to the "defined" sun rise (or what is officially recognized as the time of sun rise). Such conventions are necessary otherwise a house one block away from another would actually be different in time by several seconds. Solar time, on the other hand is unique to each particular longitude. Consequently, to calculate the sun's position, first the local solar time is found and then the elevation and azimuth angles are calculated. [2] [6]

1) Local Solar Time (LST) and Local Time (LT)

Twelve noon local solar time (LST) is defined as when the sun is highest in the sky. Local time (LT) usually varies from LST because of the eccentricity of the Earth's orbit, and because of human adjustments such as time zones and daylight saving.

2) Local Standard Time Meridian (LSTM)

The Local Standard Time Meridian (LSTM) is a reference meridian used for a particular time zone and is similar to the Prime Meridian, which is used for Greenwich Mean Time. The LSTM is illustrated below.

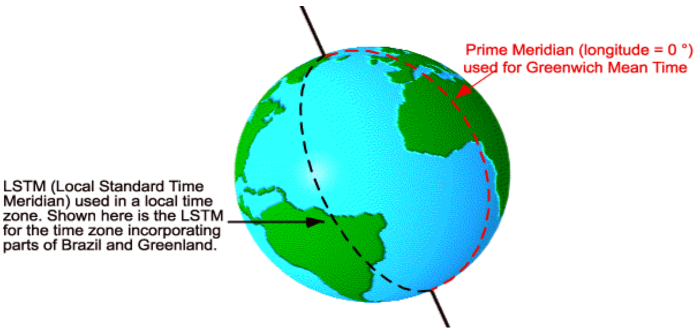

Figure.1. Local standard time meridian [2]

The (LSTM) is calculated according to the equation:

$$LSTM = 15° \cdot \Delta T_{GMT}$$

where ΔTGMT is the difference of the Local Time (LT) from Greenwich Mean Time (GMT) in hours.

3) Equation of Time (EoT)

The equation of time (EoT) (in minutes) is an empirical equation that corrects for the eccentricity of the Earth's orbit and the Earth's axial tilt. [6] [2]

$EoT = 9.87\sin(2B) - 7.53\cos(B) - 1.5\sin(B)$

Where,

$$B = \frac{360}{365}(d - 81)$$

In degrees and d is the number of days since the start of the year. The time correction EoT is plotted in the figure below.

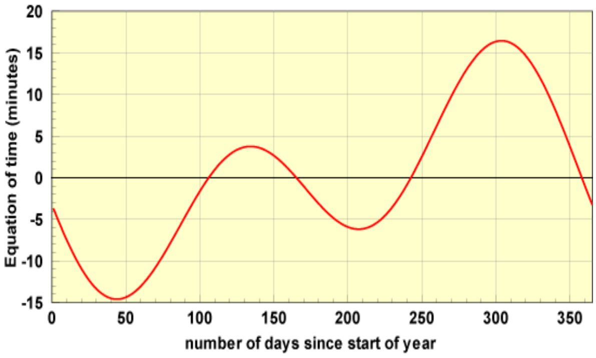

Figure.2. Time correction EoT [2]

Figure.3. Design of sundials [2]

Sundials include the equation time as a table to provide the correct time throughout the year. The other time corrections are either incorporated into the design of the sundial or given as a constant offset.

4) Time Correction Factor (TC)

The net Time Correction Factor (in minutes) accounts for the variation of the Local Solar Time (LST) within a given time zone due to the longitude variations within the time zone and also incorporates the EoT above.

$$TC = 4(Longitude - LSTM) + EoT$$

The factor of 4 minutes comes from the fact that the Earth rotates 1° every 4 minutes.

5) Local Solar Time (LST)

The Local Solar Time (LST) can be found by using the previous two corrections to adjust the local time (LT). [6]

$$LST = LT + \frac{TC}{60}$$

6) Hour Angle (HRA)

The Hour Angle converts the local solar time (LST) into the number of degrees which the sun moves across the sky. By definition, the Hour Angle is 0° at solar noon. Since the Earth rotates 15° per hour, each hour away from solar noon corresponds to an angular motion of the sun in the sky of 15°. In the morning the hour angle is negative, in the afternoon the hour angle is positive. [6]

$$HRA = 15°(LST - 12)$$

7) Declination

The declination angle has been previously given as:

$$\delta = 23.45° \sin\left[\frac{360}{365}(d - 81)\right]$$

Where d is the number of days since the start of the year.

8) Elevation and Azimuth

$$Elevation = \sin^{-1}[\sin\delta \sin\varphi + \cos\delta \cos\varphi \cos(HRA)]$$

$$Azimuth = \cos^{-1}\left[\frac{\sin\delta \cos\phi - \cos\delta \sin\phi \cos(HRA)}{\cos\alpha}\right]$$

III. OVERVIEW OF SOLAR IRRADIANCE

Solar Irradiance is a measure of how much solar power you are getting at your location. This irradiance varies throughout the year depending on the seasons. It also varies throughout the day, depending on the position of the sun in the sky, and the weather. Solar insolation is a measure of solar irradiance over of period of time - typically over the period of a single day. Irradiance is the amount of light energy from one thing hitting a square meter of another each second. Photons that carry this energy have wavelengths from energetic X-rays and gamma rays to visible light to the infrared and radio. It can be measured for any glowing object, including stars, the Moon, and the overly bright high beams of an oncoming car. Human beings radiate primarily infrared light; an infrared image of a human shows a very active heart and mind. The solar irradiance is the output of light energy from the entire disk of the Sun, measured at the Earth. The solar spectral irradiance is a measure of the brightness of the entire Sun at a wavelength of light. Important spectral irradiance variations are seen in many wavelengths, from the visible and IR, through the UV, to EUV and X-ray. As we look at the solar irradiance we should remember that space weather is related to ionization, while climate is related to absorption of heat. Measuring the spectral irradiance is important because different wavelengths (or colors) of sunlight are absorbed in different parts of our atmosphere. We feel warm because of the visible and infrared radiation that reaches the surface. Ultraviolet light creates the ozone layer and is then absorbed by that ozone. Higher still ultraviolet light creates the thermosphere, which is ionized by light at the short wavelengths of the extreme ultraviolet (EUV). Because radio communications are affected by the created ions, changes in the solar EUV output are a primary Space Weather concern. Energy from other sources also enters our atmosphere. A table of some of them is shown below. Note that the energy input from Joule heating, a coupling of the ionosphere to the magnetosphere, can be about the same as from solar EUV. [1]

IV. SOLAR PANEL TILT ANGLE SCALE

A solar photovoltaic module generates more electrical power when more sunlight power incidents on it. The sunlight power incident on a module depends not only on the power contained in the sunlight but also on the angle between the module and the sun's rays. When the sun's rays fall normally on the module's surface, the incident sunlight power is maximum. The amount of sunlight power incident on the module's surface is the component of the incoming sunlight power perpendicular to the module's surface. The following fig.1 shows ways to calculate the sunlight power incident on a module's surface.

Smodule = Sincoming Sin(α+β)

Where,

Sincoming is the incoming sunlight power, Smodule is the incident sunlight power on the module's surface, α is the sun's elevation angle and β is the tilt angle of the SPV module. [4]

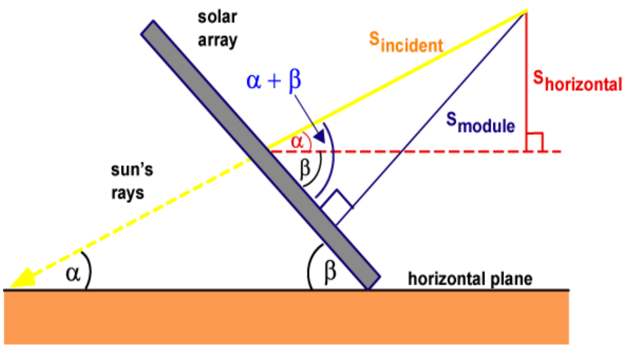

Figure.4. Fundaments of sun rays on tilt surface [3]

- **Measurement of Sunlight Power incident on SPV Module's surface**

The sun's position in the sky is defined by two angles: Altitude & Azimuth. Because of the earth's tilt, the path that the sun travels changes throughout the year. It follows its lowest path at the winter solstice (December 21 in northern hemisphere & June 21 in southern hemisphere). Following the winter solstice, the sun traces a progressively higher path in the sky until it reaches its highest path on summer solstice (June 21 in northern hemisphere & December 21 in southern hemisphere). Following the summer solstice, the sun's path become lower every day until it again reaches its lowest path on winter solstice

- **Significance of the Tilt Angle Scale**

A solar photovoltaic module collects the maximum solar radiation when the sun's rays strike it at right angles. As the SPV module is tilted away from perpendicular alignment to the sun's rays, less solar energy is received. However, a small deviation (± 5°) away from the ideal tilt will not affect energy output much. The optimal orientation for a solar energy system depends on the site latitude, date & time of the year. Sun tracking mechanism is not cost-effective but an adjustable (tilt angle) solar photovoltaic modules mount (south facing in northern hemisphere & north facing in southern hemisphere) will be cost-effective. The SPV modules that are used to produce electricity over the year are usually tilted at an angle equal to the latitude of the site. With this tilt angle the modules produce optimum energy output only at equinoxes (on March 21 & September 22). On other dates the modules do not collect sunlight as efficiently. [4] [6]

V. CALCULATION AND RESULT

Table.1. Average Solar Irradiance
Dombivli [19^0 13'8" NL,73^0 4'42" EL]

Months	Solar irradiance Kwh/m2/day
Jan	4.93
Feb	5.61
Mar	6.32
April	6.60
May	6.52
June	4.60
July	3.55
Aug	3.44
Sept	4.29
Oct	5.13
Nov	4.89
Dec	4.42

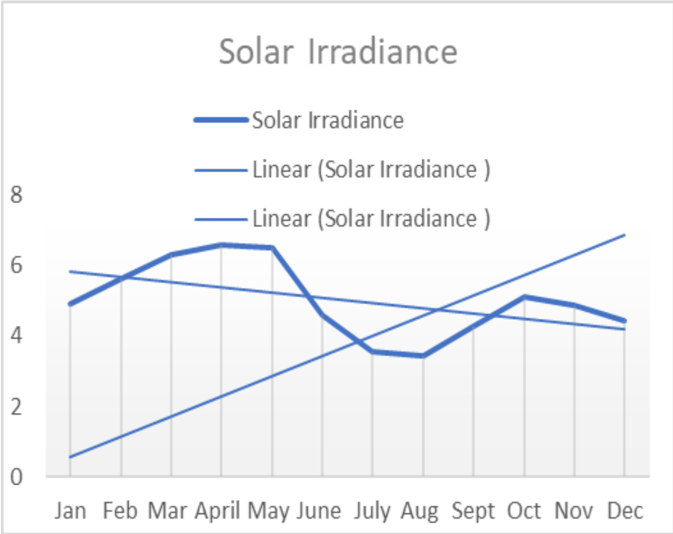

Figure.5. Annual Solar Irradiance analysis

The result shows that Mean Irradiation is **5.025 kWh/m2/day** for the Dombivli, Maharashtra. Solar angle calculator has used to calculate the Irradiance. [5]

Table.2. Optimum tilt angle Calculation
Dombivli [19^0 13'8" NL, 73^0 4'42" EL]

Months	Degrees from vertical [In degree]	Optimum tilt angle [In degree}
Jan	55	35
Feb	63	27
Mar	71	19
April	79	11
May	87	3
June	94	-4
July	87	3
Aug	79	11
Sept	71	19
Oct	63	27
Nov	55	35
Dec	48	42

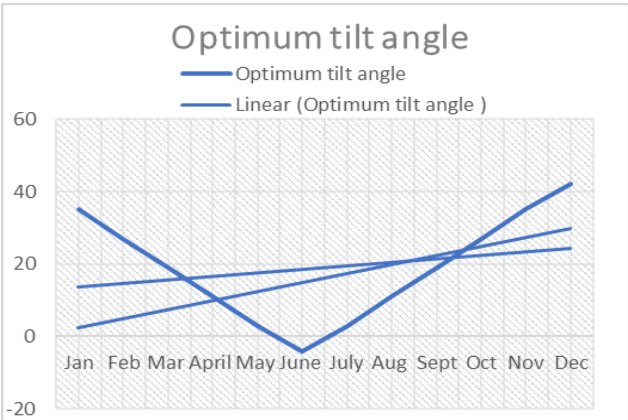

Figure. 6. Annual optimum tilts angle analysis

The result shows that **Optimum Tilt angle is 19^0** for the Dombivli, Maharashtra. Solar angle calculator has used to calculate the Irradiance. [5]

VI. CONCLUSION

Solar energy if properly utilized can be used as an effective alternative source of energy. The maximum utilization of solar energy depends upon determining the optimum tilt angle of the solar panel. By proper calculation and computer programs, the solar Irradiance and optimum tilt angle for any geographical location can be tracked. Thus, a clear idea about the Calculation of solar irradiance and tilt angle of solar panel for any location can be obtained to maximize the output of the system.

VII. REFERENCES

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