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Research Paper

Calculate the optimum tilt angle through an experimental and numerical approach of solar PV module using MATLAB

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Abstract:
In this paper, the main focus is to find out the optimum tilt angle of Jankipuram Vistar Lucknow having a latitude of 26.92 degrees north and a longitude of 80.95 east through an experimental setup approach and numerical approach of a solar photovoltaic module of 10 watts. Also, show the thermal effect of irradiation of the sun on the solar panel using Ansys software. This setup is shown a variety of angles between 0 degrees to 90 degrees. After performing result shows that numerically it is 49.56 degrees and experimentally it is 46 degrees. This paper also shows how to overcome from shading effect.

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I. Introduction:

In the whole world, we are facing the crisis of energy mainly in the non-renewable resources of energy so we are heading towards the renewable resources of energy but the main drawback of non-renewable energy is that it covers more landmass to generate a certain amount of energy as compared to non-renewable energy resources to overcome this author design a solar tree in their paper [1]. Photovoltaic (PV) systems generate electricity via the photovoltaic effect when sunlight hits electrons lose in materials that make up the solar cells. As such, whenever a cell or panel does not receive sunlight due to a shaded obstruction, it lowers the amount of electricity generated by that solar section. This is what is known as PV system shade loss.[2]Such obstructions can come from a variety of sources: Nearby objects, such as trees, antennas, or poles “Self-shading” from other PV panel rows. Skyline shading from the terrain surrounding the installation site. Other factors such as panel orientation, soiling, or differential aging Optimal solar tree design for increased flexibility in seasonal energy extraction due to this we can save more landmass as a comparison to the normal solar PV module.[3], [4]

In India, Uttar Pradesh, Lucknow which is highly populated density wise and also polluted at the same time as per reports of CPCB AQI of Lucknow is 161 and it is increasing year by year. So to get over this we have to install solar power trees in parks, roadsides, at the railway station but the main problem of the solar power tree is to get the optimum tilt angle of a specific location, so this paper is heading towards the solution of a problem. In India, the solar power trees are developed first by CSIR- CMERI Durgapur West Bengal.[5]

Renewable energy plays an important role in a pollution-free environment and it is the major alternative power from the sun in comparison to other sources of renewable energies. Solar energy is the best option to generate pollution-free electricity, lasts for a lifetime, and is easily available. We generate the power from sunlight by using solar panels.[3]

Keywords-
AQI-air quality index
CPCB -Central pollution control board
CMERI-Central Mechanical Engineering Research Institute
PV-Photovoltaic

Nomenclature:
KW= kilowatt
Φ= Latitude
ω= Hour angle
V= voltage
ƛ= lambda
i= current
δ =Solar declination
θ= Incident angle

Table 1. A comparison between conventional solar PV and solar power tree:[4]

S.No	Parameters	Flat fixed panel	Solar tree
1	Land used	It uses a large piece of land	It required a very small area of land
2	Cost	It cost is less because of its simple design	It has a complex design so more cost
3	Amount of irradiance taken per m^2	Less irradiance is absorbed	More irradiance is absorb
4	Shading	It has less effect on shading	As the panel are oriented at any angle some shading is present
5	Structure	Simple design and no improvement	Very good design
6	Orientation of panel	If the angle is above 20° they are efficient	If the angle is above 40°-80° solar trees are more efficient

The main aims of solar trees are -
•To conserve the land reserve
•To increase the efficiency of solar module by positioning the panel
•To create awareness between the people about solar energy

So here this article presents how to utilize maximum energy radiated from the sun and also and also justify the optimum tilt angle of the solar power tree because optimum tilt angle is very necessary to absorb maximum radiation from the sun.

So, I'm taking only one solar PV module of the solar power tree and further calculating the optimum tilt angle using the experiment rig and through mathematical calculation end its analysis on ANSYS software as well as MATLAB software.

1. Validation through Numerical Approach:[6]

The amount of solar energy incident on a solar collector is the sum of the beam, diffuse, and ground reflected radiation. In many research, the contribution of ground reflected energy was neglected in the estimation of solar global radiation, because of its slight value. Over the last few years, many replicas have been presented to predict solar radiation on inclined surfaces. Some of these models apply to specific cases and require special measurements and some are limited in their scope.

The calculation method of beam radiation on tilted surfaces is the same for all models. The only difference exists in the determination of the diffuse radiation for estimation of solar global radiation. Accessibility of solar diffuse radiation on a horizontal surface is an important subject in the use of these suggested models for the estimation of solar diffuse radiation on tilt surfaces. Yet, many meteorological sites in India only record the solar global radiation on a horizontal surface. [7], [8]

Another important subject is disregarding the effect of location altitude on solar global radiation on horizontal and tilt surfaces. This is another important advantage of applying these models to India, since most parts of India have a considerable plain, and the current models are applicable for the plain as well as hilly areas. Therefore, a model described in the following section is used in this study to recuperate the aforesaid problems.
To obtain optimum tilt angle using a mathematical approach:
The declination angle ω for any day (n) of the year can be obtained as follows:
$\delta = 23.45 \sin \{(360/365) * (284+n)\}$
Where n= Where n represents the day of the year and 1st January is accepted as the start
The hour angle of sunrise (ω): $\boldsymbol{\omega = \cos^{-1}[-\tan\emptyset\ \tan\delta]}$
Φ=latitude of location on earth
Total Day length (t day) = $((\mathbf{2}*\boldsymbol{\omega})/(\mathbf{15°}))$

Zenith angle in 3d: (θ z) Vertical angle between the beam ray's direction and a line perpendicular to the horizontal plane.

$\theta z = \sin\Phi \sin\delta + \cos\Phi \cos\delta \cos\omega$

To find out the proper placing of the panel with help of tracking/tilt angle we have to get incidence angle(θ) and tilt angle(β)

If $\boldsymbol{\beta \neq 0}$ *then*

$$\cos\theta = \sin(\emptyset - \beta)\sin\delta + \cos(\emptyset - \beta)\cos\delta\cos\omega$$

β= mod[Φ-δ]

1.1 Now let us take the consideration of city Jankipuram extension Lucknow whose

Latitude: 26.92 north   Longitude: 80.95 east

Calculating the value of tilt angle of 5 January 2022, so to calculate tilt angle first, we have to calculate the declination angle δ-

δ =23.45 sin {(360/365) * (284+n)}

δ=23.45 sin {(360/365) * (284+5)}

δ= -22.64 degree

now calculate the hour angle of 5 January (ω): $\omega = \cos^{-1}[-\tan\emptyset \ \tan\delta]$

here Φ=latitude of location that is 26.92 degree

ω=$\cos^{-1}[-\tan 26.92 \ \tan -22.64]$

ω=77.7 degree

Total Day length (t day) = ((**$2*\omega$**)/ (**15**°))

t day = (2 *77.7) / 15 = 10-hour 36 min day length

now tilt angle β= mod[Φ-δ]

β= mod [26.92- (-22.64)]

β= 49.56 degree So, after using the numerical approach we have to get the optimum tilt angle of Jankipuram extension which is 46.56 degree

2. Validation through Experimental Setup:[4]

This setup aims to measure the current and voltage using a Multi Meter and then calculate power through the given formula-

[Power= V *I] where V= voltage in volt, I= current in ampere

Tilt angle (β) is measured through an inclinometer application using mobile.

Figure 1: Setup of PV module calculating current and voltage

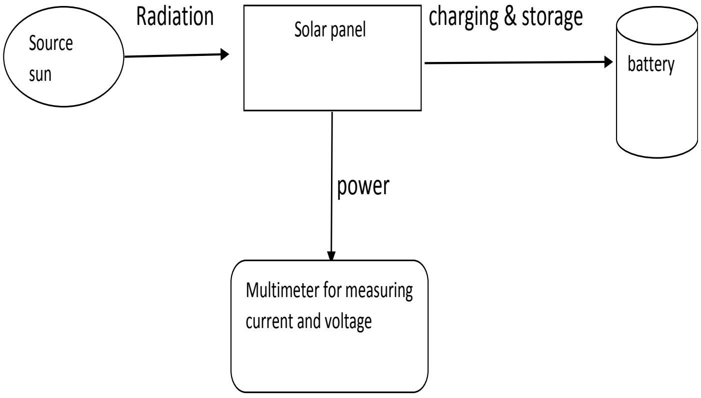

Figure 2 Block diagram of the experimental setup

2.1Test setup specification:
The material used: Polycrystalline material is used to get a more effective power output from the given setup.
Rated max power: 10 watt, Rated Current Imp: 0.6 A
Rated Voltage Vmp: 16.8V, Operating Temperature: 45+/- 2℃ , Digital Multi Meter

2.2 RESULT of experimental setup and calculation:

We can see that at the 7th reading we get the maximum output of the solar PV module that is 10 watts and get optimum tilt angle is 46 degrees. To find the secure tilted angle that gives higher produced electricity by photovoltaic cells ended days of the month, the tilted angle will vary over a range of 0°–60° with a phase of 4°. shows that as the tilted angle increases, produced power will also increase due to development in the expanse of normal solar radiation that incidents to the cell's surface, the generated power reaches a value of which the tilted angle increases and the created power decreases (maximum value)
Reading taken on 5 January 2022 at noon using experimental setup:

TILT ANGLE(B)	CURRENT(A)	VOLTAGE(V)	POWER(WATT)
22	0.535	11	5.41
26	0.527	12	6.33
30	0.554	13	7.21
34	0.570	14.2	8.10
38	0.593	16	9.50
42	0.60	16.2	9.74
46	0.61	16.6	10
50	0.532	14.32	7.62
54	0.493	13	6.42
60	0.40	12.7	5.09

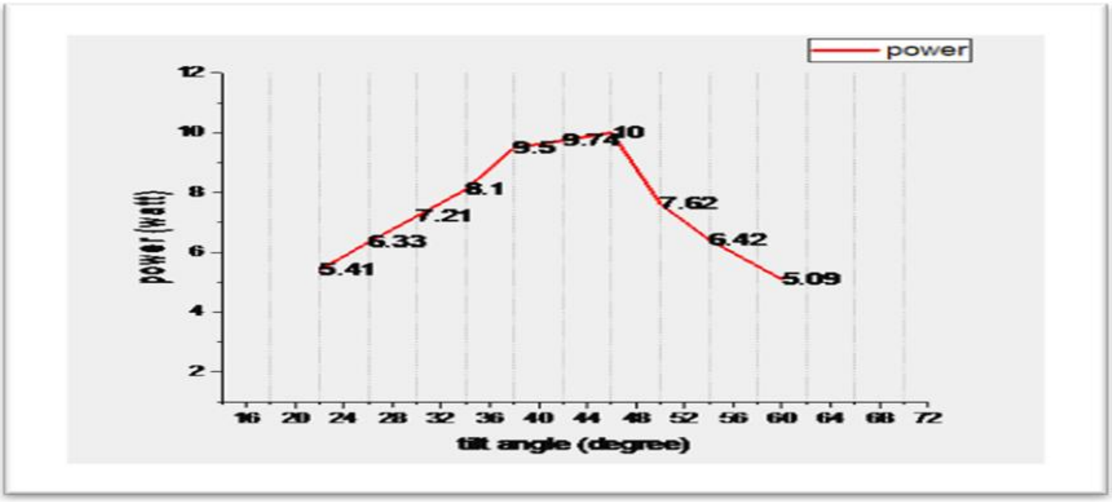

Figure 3: Graph on origin shows maximum tilt angle at a rated power of solar PV that is 10 watts.

Figure 4: increase the angle gradually, power is first increases then decreases.

2.3Validation through Thermal Effect on Ansys software:

We can see the maximum irradiation at 46 degrees in the screenshot of Ansys software and easily validate the numerical calculation as well as

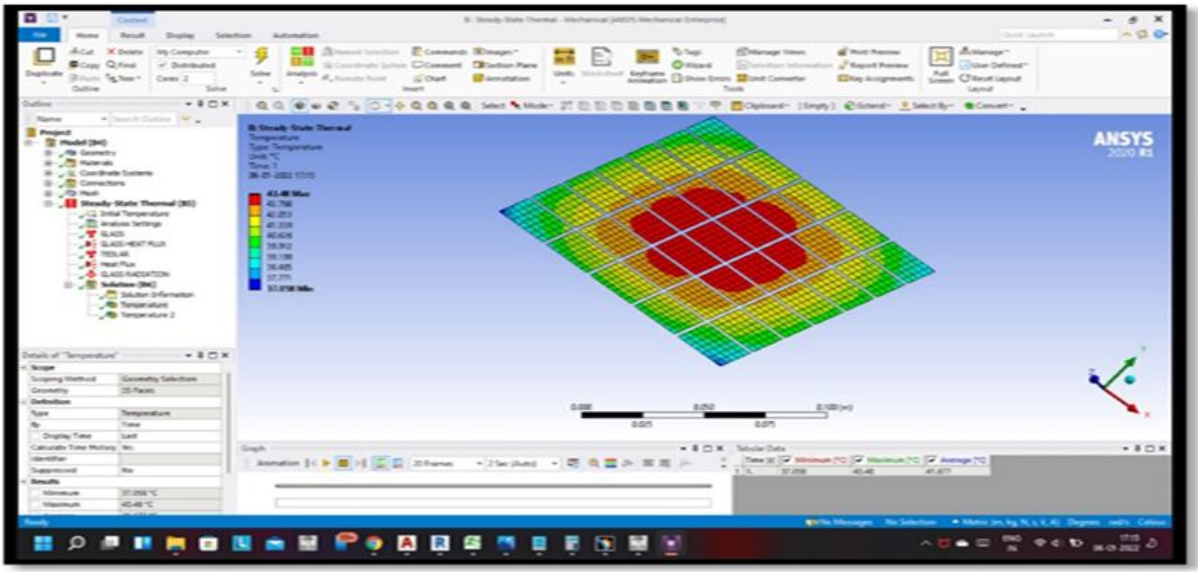

Figure 5: Screenshot of Ansys software showing maximum irradiation at 46 degree

experimentally values. We concluded that as the tilt angle increases the power of a particular photovoltaic fuel cell is first increases and then decreases due to a rough prediction of the idea of a particular day.

3.Approach using MATLAB software:[9]

Estimate the *power output* from a typical solar panel installation on a specific date, time, and location by calculating the following:

- Solar time
- Solar declination and solar elevation
- Air mass and the solar radiation reaching the earth's surface
- Radiation on a solar panel given its position, tilt, and efficiency
- Power generated in a day and over the entire year

Use the consequences of these calculations to plot solar and panel radiation for the sample day and location. Then, plot the predictable panel power generation ended a year. To rationalize the analysis, use two MATLAB functions created for this example: solar Correction and panel Radiation.

3.1 Solar Time

Power generation in a solar panel is contingent on how ample solar radiation grasps the panel. This in turn is contingent on the sun's position compared to the panel as the sun transfers across the sky. For example, suppose that you want to calculate power output for a solar panel on 5 January 2022 Lucknow Uttar Pradesh India.

To calculate the sun's position for an assumed date and time, use *solar time*. Twelve-noon solar time is the time when the sun is highest in the sky. To calculate solar time, apply a correction to local time. That correction has two parts:

- A term that modifies for the difference between the observer's location and the local meridian.
- An orbital term related to the earth's orbital eccentricity and axial tilt.

3.2 Solar Declination and Elevation

The solar declination (δ) is the angle of the sun comparative to the earth's equatorial plane. The solar declination is $0°$ at the vernal and autumnal equinoxes and rises to the extreme of at the summer solstice. Calculate the solar declination for a given day of the year (d) using the equation

$$\delta = \sin^{-1}\left(\sin(23.45)\sin\left(\frac{360}{365}(d-81)\right)\right)$$

Then, use the declination (δ), the latitude (ϕ), and the *hour angle* (ω) to calculate the sun's elevation (α) at the current time. The hour angle is the number of degrees of rotation of the earth between the current solar time and solar noon.

$$\alpha = \sin^{-1}(\sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega)$$

Calculate the time of sunrise and sunset in Standard Time employing the sun's declination and the local latitude.

$$sunrise = 12 - \frac{\cos^{-1}(-\tan\phi\tan\delta)}{15°} - \frac{TC}{60} \qquad sunset = 12 + \frac{\cos^{-1}(-\tan\phi\tan\delta)}{15°} - \frac{TC}{60}$$

3.3 Air Mass and Solar Radiation

As light from the sun permits through the earth's atmosphere, about of the solar radiation is captivated. Air mass is the length of the path of light through the atmosphere (Y) relative to the shortest possible path (X) when the sun's elevation is 90°, as shown in the diagram below. It is a function of solar elevation (α).

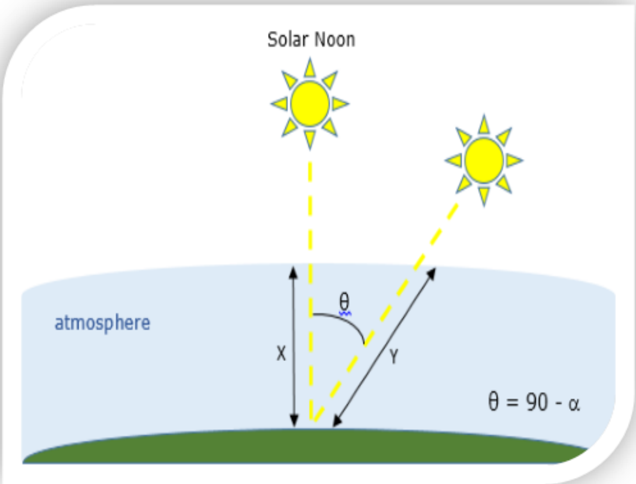

Figure 6: Show solar irradiation

The bigger the air mass, the less radiation reaches the ground. Calculate the air mass employing the equation

$$AM = \frac{1}{\cos(90-\alpha) + 0.5057(6.0799+\alpha)^{-1.6364}}.$$

Then, calculate the solar radiation reaching the ground (in kilowatts per square meter) employing the empirical equation

$$sRad = 1.353 * 0.7^{AM^{0.678}}.$$

3.4 Solar Radiation on Fixed Panels

Panels installed with a solar tracker can move with the sun and receive 100% of the sun's radiation as the sun moves across the sky. However, most solar cell installations have panels set at a fixed azimuth and tilt. Therefore, the real radiation attainment of the panel also is contingent on the solar azimuth.

The solar azimuth (γ) is the compass way of the sun's position in the sky. At solar noon in the Northern hemisphere, the solar azimuth is $180°$ consistent to the direction south. Calculate the solar azimuth using the equation

$$\gamma = \begin{cases} \cos^{-1}\left(\dfrac{\sin\delta\cos\phi - \cos\delta\sin\phi\cos\omega}{\cos\alpha}\right) & \text{for solar time} \leq 12 \\ 360° - \cos^{-1}\left(\dfrac{\sin\delta\cos\phi - \cos\delta\sin\phi\cos\omega}{\cos\alpha}\right) & \text{for solar time} > 12 \end{cases}$$

In the northern hemisphere, a typical solar panel installation has panels oriented toward the south with a panel azimuth (β) of. At northern latitudes, a typical tilt angle (τ) is 45. Calculate the panel radiation for static panels from the entire solar radiation using the equation

$$pRad = sRad[\cos(\alpha)\sin(\tau)\cos(\beta - \gamma) + \sin(\alpha)\cos(\tau)]$$

3.5 Panel Radiation and Power Generation for a Single Day
Modify parameters using interactive controls. Display plots together with the code that produced them.

3.5.1 Panel Radiation
For a given day of the year, calculate the total solar radiation and the radiation on the panel. To simplify the analysis, use the panel Radiation function. Try changed dates to see how the solar and panel radiation change depending on the time of year.

3.5.2 Power Generation:
So far, the calculations assume that all of the radiation reaching the panel is available to generate power. However, solar panels do not convert 100% of available solar radiation into electricity. The efficiency of a solar panel is the fraction of the available radiation that is converted. The efficiency of a solar panel depends on the design and materials of the cell.

Typically, a residential installation includes $20\,\mathrm{m}^2$ solar panels with an efficiency of 25%. Modify the parameters below to see how efficiency and size effect panel power generation.

3.6 Power Generation for the Whole Year
Hover over a plot to interact with it. Interacting with a plot in the Live Editor will generate code that you can then add to your script.

Repeat the calculation to estimate power generation for each day of the year.

Panel Tilt and Latitude
Use a heatmap to regulate how panel tilt touches power generation. The figure below shows that the ideal panel tilt for any position is about $5°$ less than the latitude.

9. Result of using MATLAB software 2019b:[7], [10]

Energy collection using solar collectors can be enhanced by setting the collector inclination to the optimum tilt angle. It is likely to reach the maximum getting energy by daily alteration of tilt angle. However, monthly, seasonal, semi-annual, or yearly tilt angle adjustments are the substitute solutions in case of operative limitations. In this study, the optimum tilt angles for a specified period were determined using a mathematical model and by developing computer packages using MATLAB.

After running the MATLAB software using above codes as input already
localTime = datetime 05-Jan-2022 12:00:00 PM
solarTime = datetime 05-Jan-2022 12:20:32
Solar Declination = -23.0647 Solar Elevation = 39.7822
Sunrise = 06:29:24 AM, Sunset = 16:49:30 PM
Air Mass = 1.5605 Solar Radiation = 0.83531 kW/m^2
Solar Azimuth = 185.9895
Panel Radiation = 0.80401 kW/m^2

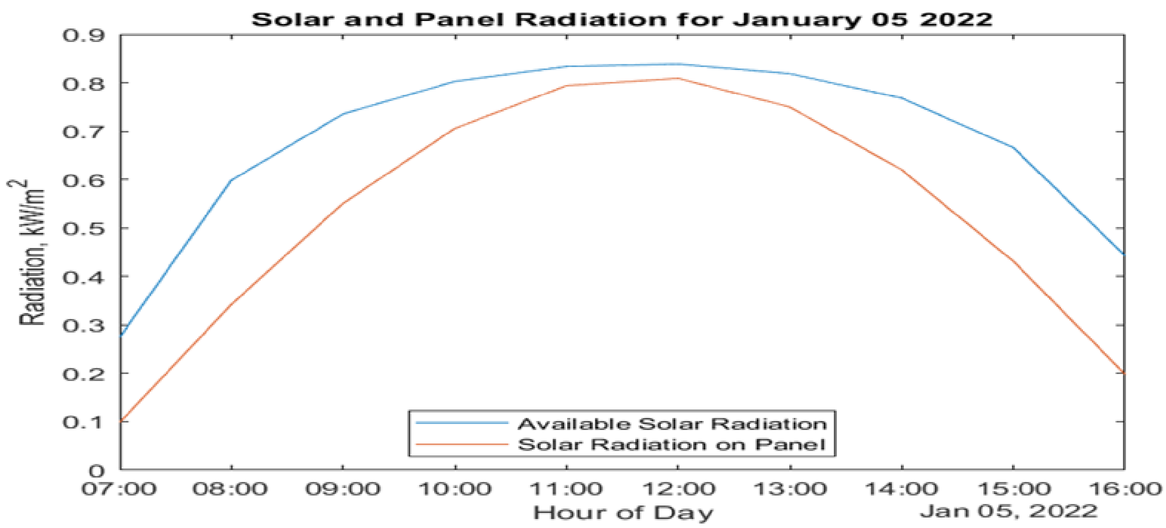

Figure 7: Expected daily electrical output for 05-Jan-2022 = 25.7534 kW-hrs

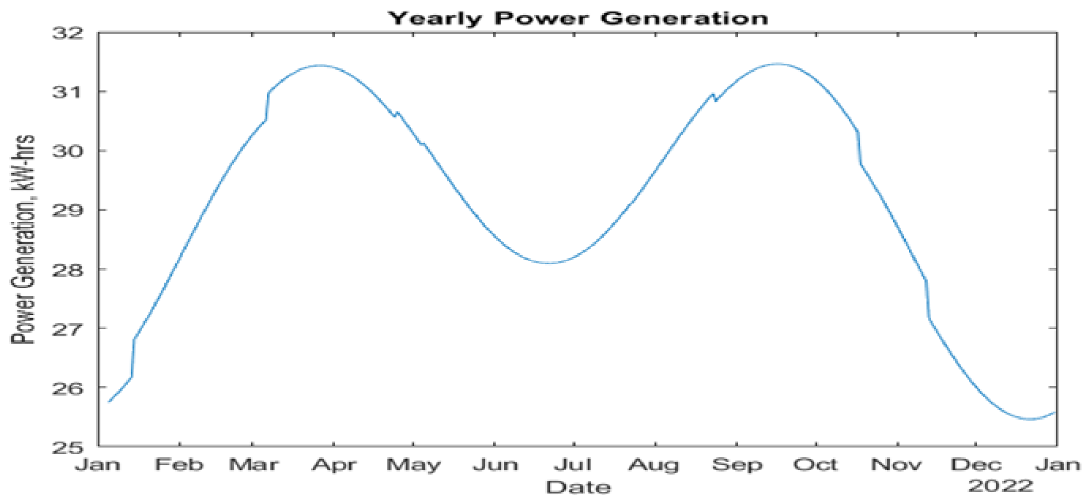

Figure 8: Expected annual power output = 10521.8637 kW-hrs

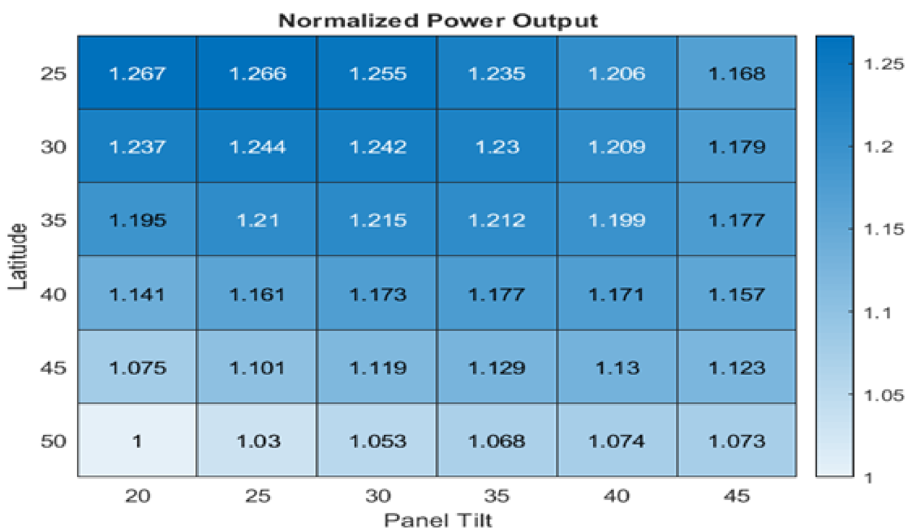

Figure 9: Showing maximum tilt angle light colors

II. Conclusion:

This work describes a new application of solar cells by using MATLAB/Simulink of photovoltaic arrays and modeling using experimental data. To build a photovoltaic panel was used the Solar Cellblock and the power produced by a photovoltaic array is affected by changing irradiance. The implemented model was validated through simulation.

The optimum value experimentally is near about 46 $degree$ .The optimum value through calculation is near about 49.56 degrees. In this study, the tilt angles for Jankipuram Lucknow city are calculated using solar angles and the mathematical values of the tilt angles are compared with the experimental results.

The error between experimental values and theoretical values is near about 3.56 degrees. We conclude that by finding the optimum tilt angle of their geographical area we can easily utilize maximum irradiation directs on the solar panel of a power tree.

It helps to reduce the shading of a solar PV module and generate maximum power output from the solar panel by calculating the correct and optimum values of tilt of a particular location as per the use of different users.

Conflict of interest:
There is no conflict of interest from the author's side

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