IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676, p-ISSN: 2320-3331, Volume 16, Issue 5 Ser. I (Sep. – Oct. 2021), PP 52-58
www.iosrjournals.org

Investigating the optimal tilt of photovoltaic solar panels in Jay Jalaram, Ahmedabad

Rajveer S Dhingra, Varyam Gupta
The Doon School, Dehradun

Abstract
Solar Panels are gaining popularity with time and have made their mark in the sector of renewable energy and power generation. One of the key factors that play a role in varying the efficiency of a solar panel is the tilt angle when the solar panel is installed. The optimum tilt angle may be regarded as a gamechanger with respect to the efficiency of a solar panel. This paper aims to provide a brief summary about the functioning of a solar panel and the various factors that may play a role in affecting the optimum usage of the technology. Moreover, the study aims to highlight one determining factor, the optimum tilt angle of a solar panel. After reviewing various existing literature on this, the research conducted analyses data samples from Jay Jalaram in Ahmedabad to find the optimum tilt angle for the location. The study links the existing models to the investigations and conclusions performed by the authors, to determine the optimum tilt angle for a latitude of 23.09°. This study will help increase the efficiency of power generation of solar panels at an industrial level in the future.

Key Words: Solar Panels, Optimal Tilt, Efficiency, Power Generation

---

Date of Submission: 08-10-2021 Date of Acceptance: 22-10-2021

I. Introduction:

Solar Panels and the technological advancements of generating electricity through renewable meansis a paradigm shift with respect to the field of energy and electricity. Amongst the numerous benefits, one key advantage to note is the nudge away from sources of non-renewable energy. With a predicted extinction of resources such as coal and Biomass, mankind has no option, but to resort to natural sources as a source of energy. This includes options from wind turbines to hydroelectricity but arguably the most efficient source is solar energy. Solar panels use a series of processes to convert natural light to electricity, and in essence, convert chemical energy to electrical energy. This process uses semiconductors to its advantage, as with their help, sunlight can activate free electrons. After which, bus bars collect the running electrons which result in electric current. Solar panels often generate Direct Current and can be converted to Alternative currents as well, with the help of an inverter.

In order to make the most of this ground-breaking technology, the efficiency of the solar panel must be operating at an optimum. The efficiency of a solar panel depends on numerous factors such as the technology, weather, temperature, locationetc. however one of the crucial factors that can be controlled is the angle of installation of the solar panel and its orientation. This also exposes a loophole in the renewable energy systems today where maximum attention is being paid to the technological developments of solar panels, however, the installation process of solar panels and its effect on the panels' efficiency is often undermined and overlooked. Hence, it becomes desirable to investigate the optimal tilt angle at which the solar panels are able to maximise their energy output. Since solar panels are being used worldwide at an industrial level, this paper will specifically be exploring the tilt angles that would provide optimal power generation across the year when implemented at an industrial level.

Functioning of a solar panel:

Solar panels convert solar energy to electrical energy. They do so with the help of minuscule units called solar cells or photovoltaic cells. Each of these solar cells is made out of semiconductor materials, commonly silicon because of its abundance. 2 sheets of silicon are put in between a layer of conductive material. The silicon atoms are interconnected with the help of 4 strong bonds which don't let the electrons flow, thus not allowing a current to pass. There are 2 layers of silicon, layer N with excess electrons, and layer P with extra spaces or a lack of electrons. The extra electrons can move across the junction between the 2 layers of silicon creating a positive charge on one side. Photons from sunlight with high enough energy can knock off the electrons from the bonds making them free to move. The electrons can move anywhere they want but they only

move towards the edge of the N layer because of the potential difference at the junction. A huge number of electrons can be collected at the boundary, and they can be extracted from there with the help of the conductive material. The electrons can be used to power up anything and they can then be returned to the solar cell.

Solar panels can only be placed in areas with abundant light, less cloud coverage and long sunlight hours. It should be placed near the equator where the sun rays are perpendicular to the panel and the panel is most efficient. The solar panel should face true south in the northern hemisphere and vice versa. Tall buildings, trees and shade can also hinder the functionality of the solar panels. As of now, the technology isn't as mature and the most efficient solar panel has an efficiency of 46%, while the most commonly used solar panels have an efficiency of 20% or less[1]. So, considering the place where you situate the panels is key to their functionality.

Background Theory

Study Location

The present study was carried out in the city of Ahmedabad in Gujarat, India. The city has a population upwards of 8 million people and its area is 1866 square kilometres. It is located on the banks of the Sabarmati River with sufficient sunlight falling throughout the year, with an average amount of 3020 hours of sunshine across a year[2]. Ahmedabad is situated between 21.6 to 23.4 north latitude and 71.6 to 72.9 east longitude. The location where the experiment was carried out had a location of 22.8 north latitude and 72.3 east longitude. However, since the solar panel being used is stationed facing towards north and south direction, only the north latitude is considered. The city also has one of the highest annual average solar resourcesof 5.5 to 6.0 kilowatt-hours/square meters/day[3]. Specifically, the data was collected fromShashwat Cleantech Pvt. Ltd., a solar panel production company that installed panels in JayJalaram and monitored data from the same.

Weather

Scientific theoriesagree how different angles will be prominent for different times, especially due to the effect of weather on the position of the Sun as well as its incidence. As predicted by Nfaoui and El-Hami, the seasonal optimal angles follow a trend where the optimal angles are in the following order season wise: winter > autumn > spring > summer. However, since the study was carried out in a different location, the trend might differ in India. This also depends on the amount of sun hours that fall in the city of Ahmedabad and the angle of incidence of sunlight at different weathers.

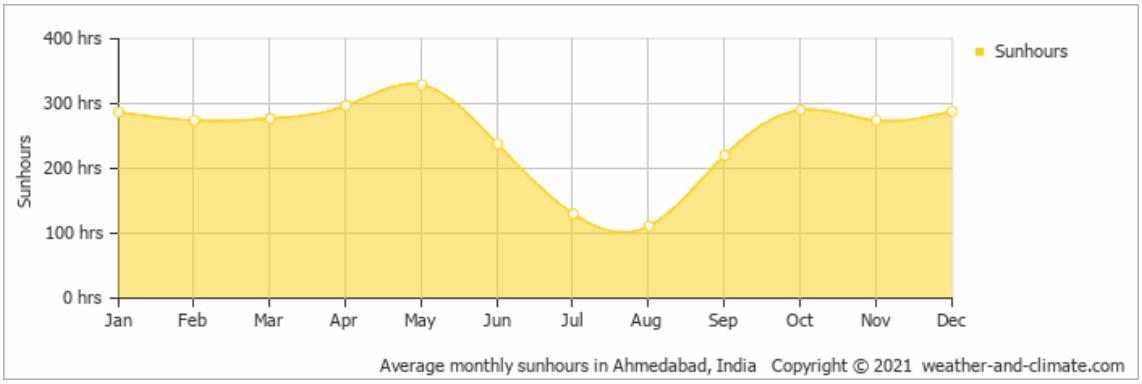

Figure 1

Previous Works

Siraki and Pillay (2012)investigated the optimum solar panel tilt at different latitudes for urban applications. After taking all concerns into consideration the paper studies the optimal angle at different latitudes through the means of a modified sky model. The results of the paper show a dependence of the angle on the latitude, weather, and surroundings in general. The study uses an algorithm previously explored byDuffieand Beckman in 2006. After modifications to the methodology, the study concludes that the knowledge of the optimum angle is essential in order to make the most of this technology. The research concludes that their results explore the reasoning behind a trend in the optimum angle and the latitude, over the course of various experimental investigations. In conclusion, they state that the optimal angle of installation for small values of latitude is close to the location's latitude. While, with increasing latitude values, the optimum tilt angle is

[1]https://www.greenmatch.co.uk/blog/2014/11/how-efficient-are-solar-panels
[2]https://weather-and-climate.com/average-monthly-hours-Sunshine,ahmedabad,India
[3]https://www.nrel.gov/docs/fy14osti/60991.pdf

smaller to capture most sunlight. Nevertheless, the study also mentions the importance of other factors which cause for a researcher to reconsider the optimum angle, few of which include the optimum azimuth, surrounding obstacles, and weather conditions.

Apart from this, there have been various studies in the past that aim to sought after a similar corelation between the two variables. Yang and Lu conducted a study in 2000 which used the anisotropic sky model for a latitude of 22.5 °to obtain the tilt angle as 20 °. Similarly, Chen et al (2005) used a different method to obtain results. They focused on an algorithm to find the optimum angle of the Chiayi province in Taiwan at a latitude of 23.5 °. Like the previous study, the optimum tilt turned out to be 20 °. In 2004, Hussein et al turned to the means of simulation and concluded that the optimum tilt angle in Cairo, Egypt was between 20 and 30 °, where the latitude is 30 °.

Two other studies were carried out in 2009 to delve deeper and find the correlation between the variables. Calabroa (2009) resorted to simulation means as well for a range of latitudes between 36 and 46 °and got interesting results. The study concluded that the optimum tilt angle is shifted by almost 10 ° with respect to the latitude of the location, pertaining to a change in 10 °. Chenga et al carried out a study in the same year, which made the most of a software package to generalize results, and not limit them to a particular latitude. The paper showed that for the latitudes below the tropic of cancer the optimum angle is almost equal to the latitudes. On the other hand, the latitudes lying at high values the tilt angle is comparatively smaller than the locations latitude in degrees and the discrepancy in readings increases.

Danandeh and Mousavi G. (2018) carried out a comparative investigation to review the main models of irradiance estimation and compare models to obtain the optimum tilt angle for cities in Iran. After using the following four models- Perez, Hay, Gueymard and Skartveit and Olseth models- the study found that the Hay and Skartveit and Olseth Models predicted the optimum angle nearest to the actual results.

All in all, after studying various sources and evaluating the multiple methods used to investigate the similar topic, the authors of this paper have cited a general trend in the corelation of the optimum tilt angle with the latitude of a particular area, as summed up above. Hence, the authors predict that the optimum angle in Ahmedabad will be around 20-22 °.

Mathematical Model

By using mathematical concepts of vectors, trigonometry, and calculus the following equations can be derived considering the Earth's axial tilt into account:

$cos^{-1}((\tan(\theta_L - \theta)\tan\theta_R)$

With the limits:

$$if\ \tan(\theta_L - \theta)\tan(\theta_R) > 1\ then \tan(\theta_L - \theta)\tan(\theta_R) = 1$$
$$if\ \tan(\theta_L - \theta)\tan(\theta_R) < -1\ then \tan(\theta_L - \theta)\tan(\theta_R) = -1$$

The equations give the following model which defines the relationship between latitude of location and optimal tilt angle of a solar panel:

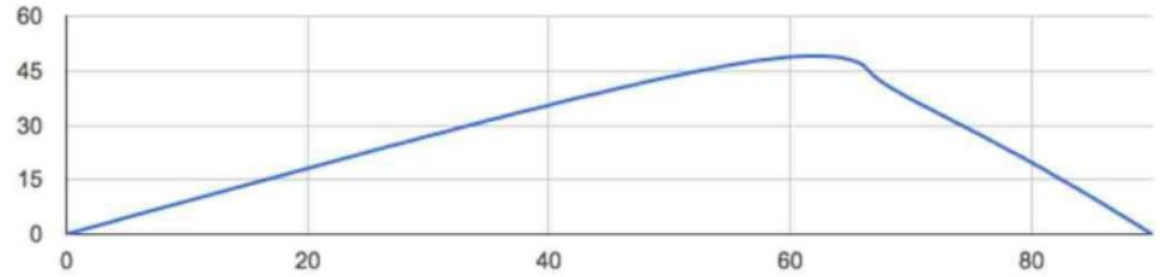

Figure 2: Latitude of Location (x) vs Optimal Tilt Angle (y)

Hence, using the model it can be theoretically assumed that the optimal tilt angle for Ahmedabad with a latitude of 23 ° will be equal to 18.76° tilt.

II. Methodology

To calculate the optimal tilt angle of solar panels, a few key factors and variables had to be controlled and kept constant to ensure standardisation. The controlled variables is further defined in Table 1

Table 1

Sr No	Controlled Variables	Variable Description	Reason
1	Module Type	Photovoltaic	This specific module was selected as it is one of the most common modules being utilised across industries in India. By keeping this module constant, the study becomes more relevant to the practical applicability of solar panels in India

2	Location	JayJalaram	The location of solar panels was fixed at a latitude 23.09 North which was the location of antemple named Jay Jalaram
3	Platform	Roof	The platform was kept as roof instead of other options such as sheds or ground, as majority of industries are implementing rooftop solar panel at a large scale
4	Facing Side / Azimuth	True South	The facing side was kept the same in order to obtain reliable data which could be compared to other data sets. A change in azimuth can alter the power generated daily by a significant amount.
5	Inverter	String-ABB	With different inverters having varied efficiency levels and processes of converting DC to AC, the inverter was fixed at String-ABB, another industrial standard used across India.

With these fixed conditions data was taken from Shashwat Cleantech Pvt. Ltd which had implemented solar panels at different angles at an industrial level. The data was then modelled for each month and the average optimal tilt across the year of 2020 was determined. The results were then compared to the theoretical models explored in previous works and scientific theory.

Data Collection

Table 2

Month	**Average Power Generation in kWh at particular Angle of Tilt of Solar Panel**					
Angle:	6°	10°	14°	18°	22°	26°
January	3.21	3.45	3.97	4.84	4.64	4.31
February	3.76	4.09	4.45	5.13	4.93	4.60
March	4.35	4.70	4.90	5.41	5.21	4.88
April	4.46	4.77	4.98	5.17	4.97	4.64
May	4.67	4.89	5.96	5.22	5.02	4.69
June	3.11	3.36	2.80	3.79	3.59	3.26
July	1.98	2.01	2.38	3.68	3.48	3.15
August	2.10	2.48	2.56	3.25	3.05	2.72
September	1.95	2.11	2.57	3.07	2.87	2.54
October	2.99	3.36	3.46	4.24	4.04	3.71
November	3.06	3.25	3.62	3.90	3.70	3.37
December	2.56	2.88	3.30	4.04	3.84	3.51
Average	3.18	3.45	3.75	4.31	4.11	3.78

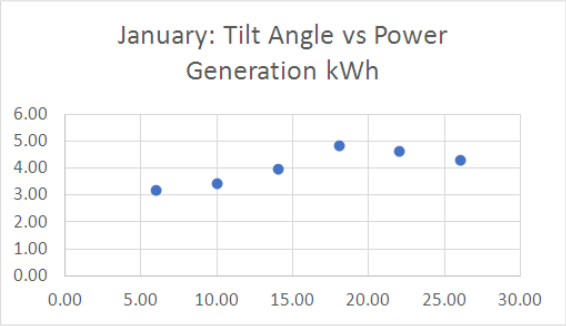

Figure 4

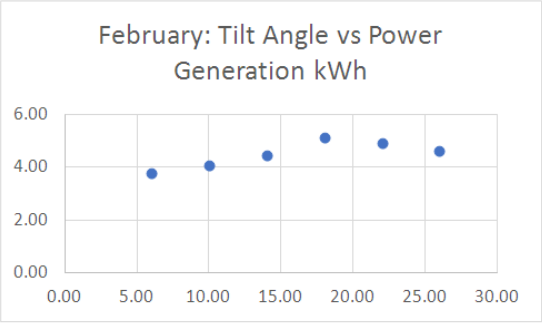

Figure 3

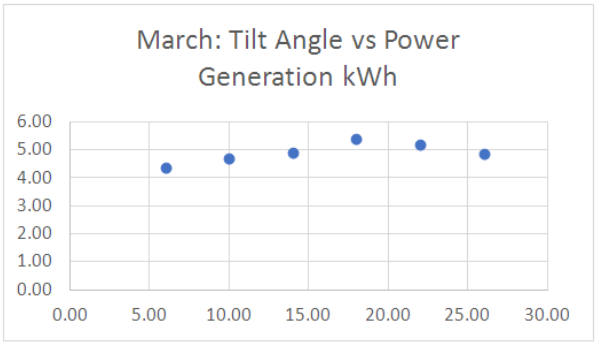

Figure 5

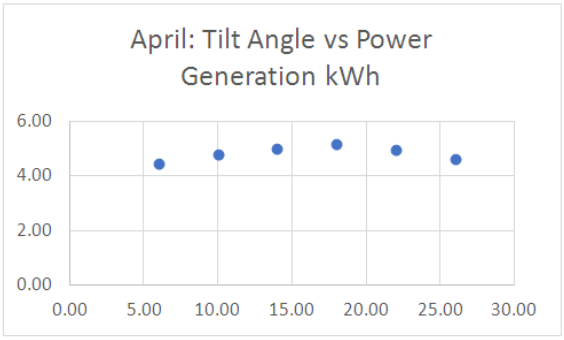

Figure 6

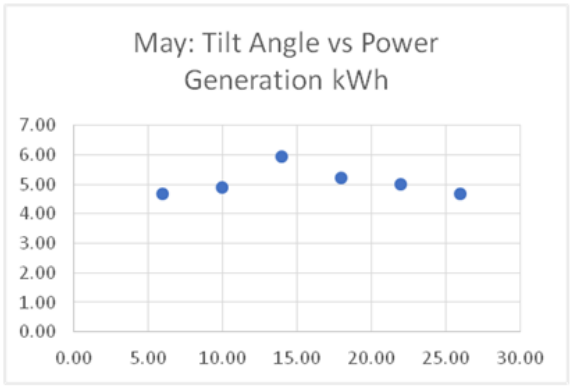

Figure 7

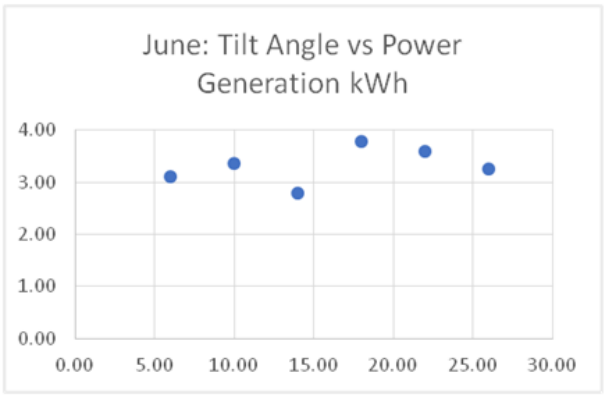

Figure 8

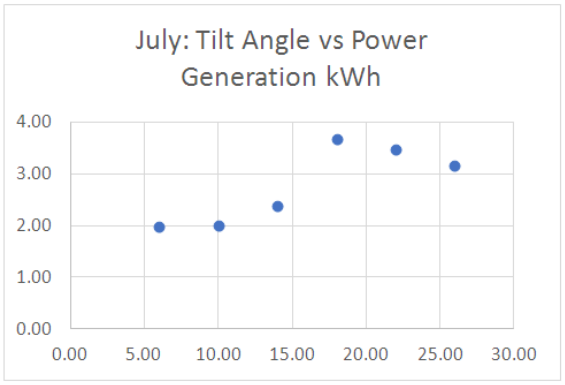

Figure 09

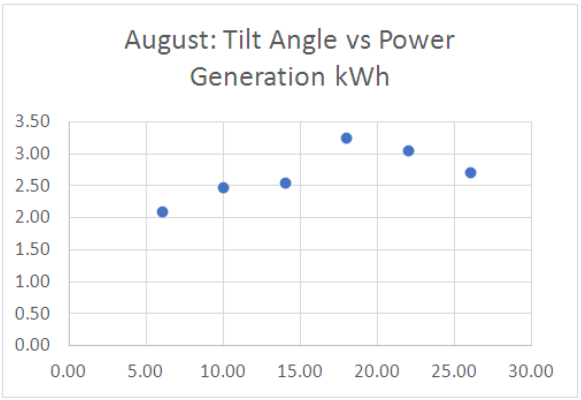

Figure 10

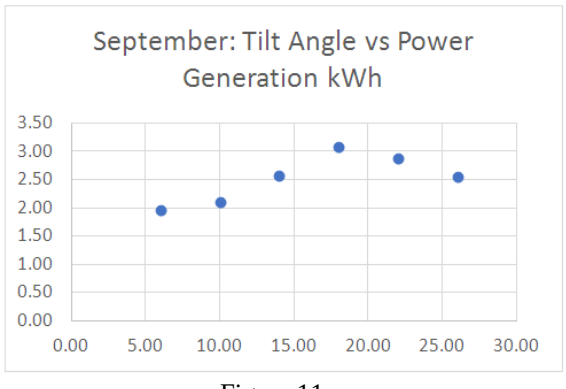

Figure 11

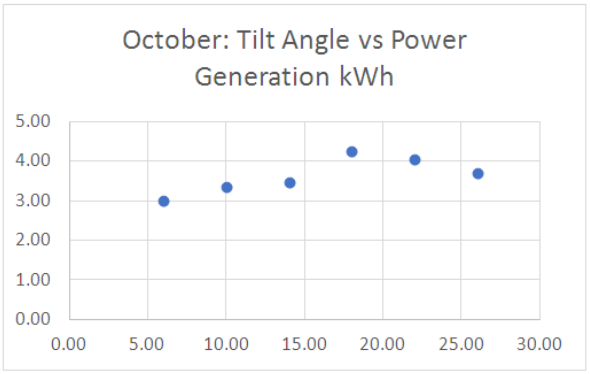

Figure 12

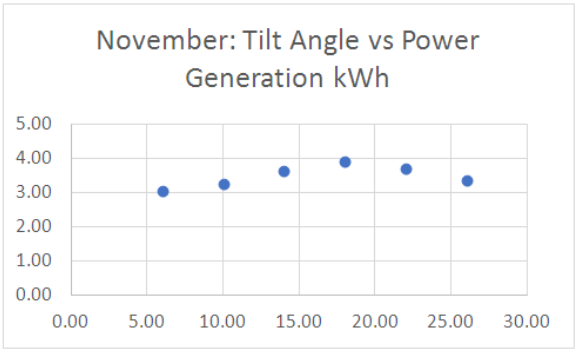

Figure 13

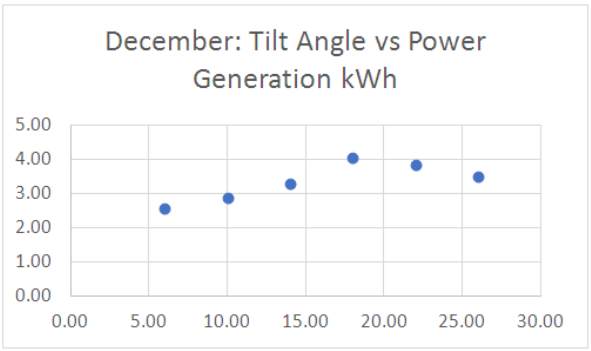

Figure 14

After breaking down the data month-wise, the research cites a similar trend in the average power generated for a particular month, corelated to the angle of tilt. After seeing a peak in all graphs at 18°, the trend is in line with the existing research. The general trend observed for power generation throughout the year showed a gradual increase in average power generation from January to May. After observing a peak in May, the power generation drops till September, and then rises again after post October. This is due to the weather conditions in those months and the amount of sunlight that is able to pass in summers and winters respectively.

Data Analysis

The data collected was then averaged over the 12 months to analyse which tilt angle provides the most power generation in kWh over the entire year. The following function was generated:

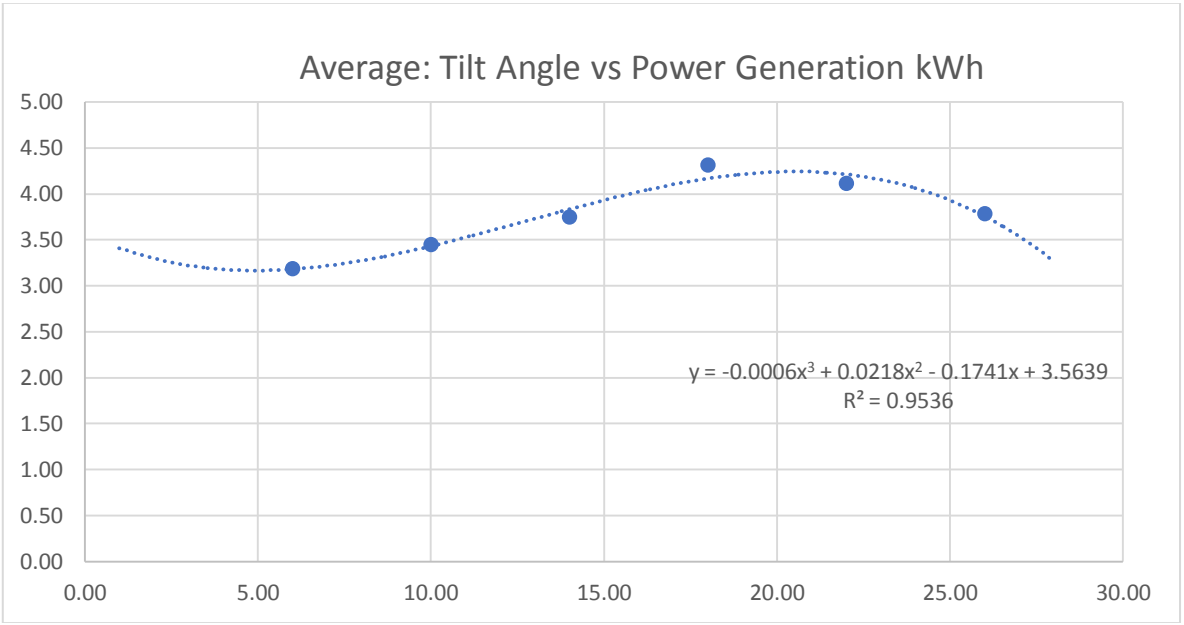

Figure 15

The function obtained was quite accurate with a relation coefficient of 0.9536 and was cubic in nature with the equation:

$$y = -0.0006x^3 + 0.0218x^2 - 0.1741x + 3.5639$$

By using differentiation as a tool for optimization, it was found that the optimal tilt angle was at 19.179 ° which produced an average of 4.01 kWh for the entire year. Hence, the optimal angle of installation in Ahmedabad, India came out as approximately 19 °.

The results match the hypothesis and conclusion derived by Siraki and Pillay that the optimal solar panel tilt angle is usually found to be near the value of the north latitude, however that willonly be the case under a narrow range of longitude values which includesthe region of India. The difference between the latitude and the optimal tilt is that of approximately 4 ° which is also under the range of the 0-to-6-degree difference that was identified by Hua et al in their study of the optimal angle in Gansu Province in China. Hence, it can be

fairly evaluated that the results meet the expected scientific theory and results produced for the past two decades.

III. Conclusion

The importance of solar panels cannot be highlighted more. The extremely essential nature of this technology is increasing in relevance. As discussed, there are a range of factors the influence the optimum use of solar panels to generate electricity efficiently. This study classifies the previous studies to evaluate a trend with one particular variable: the optimum tilt angle at a particular latitude.

After careful examination of previous studies, and research conducted with data obtained at the Jay Jalaram location in Ahmedabad, this study determines the optimum tilt angle for that location. The results of the paper lie in corelation with respect to the cited studies in the paper. In conclusion, at a latitude of 23.09°, the optimum tilt angle was 19.179°. The results are in accordance with previous works, and any discrepancies are a result of our selection of Ahmedabad city as the study location. In the long-term, research and development in the installation of solar panels in India can be further focused on in order to improve the efficiency of the panels and allow for the Indian government to meet its aims of increasing solar panel generation and utilisation.

References

[1]. Hua, Y.P., Oliphant, M., and Hu, E.J., Development of renewable energy in Australia and China: A comparison of policies and status, *Renewable Energy*, 2016, vol. 85, pp. 1044–1051.

[2]. Nann, S., Potentials for tracking photovoltaic systems and V-troughs in moderate climates, *Sol. Energy*, 1990, vol. 45, no. 6, pp. 385–393.

[3]. Yaping Hua, He, W. & Liu, P. Optimum Tilt Angles of Solar Panels: A Case Study for Gansu Province, Northwest China. *Appl. Sol. Energy* 56, 388–396 (2020).

[4]. M.J. Ahmad, G.N. Tiwari, Optimum tilt angle for solar collectors used in India, Int J Ambient Energy, 30 (2009), pp. 73-78

[5]. D.R. Myers, Solar radiation modeling and measurements for renewable energy applications: data and model quality

[6]. M.A. Danandeh, S.M. Mousavi G., Solar irradiance estimation models and optimum tilt angle approaches: A comparative study, Renewable and Sustainable Energy Reviews, Volume 92, 2018, Pages 319-330,

[7]. ArbiGharakhani Siraki, PragasenPillay,, Study of optimum tilt angles for solar panels in different latitudes for urban applications, Solar Energy, Volume 86, Issue 6, 2012, Pages 1920-1928

[8]. Yaping Hua, He, W. & Liu, P. Optimum Tilt Angles of Solar Panels: A Case Study for Gansu Province, Northwest China. *Appl. Sol. Energy* 56, 388–396 (2020).

[9]. Kadir Bakirci, General models for optimum tilt angles of solar panels: Turkey case study,Renewable and Sustainable Energy Reviews, Volume 16, Issue 8, 2012, Pages 6149-6159

[10]. J.A. Duffie, W.A. Beckman, Solar Engineering of Thermal Process, (third ed.), Wiley, New York (2006)

[11]. H. Yang, L. Lu, The optimum tilt angles and orientations of PV claddings for building-integrated photovoltaic (BIPV) applications, J. Sol. Energy Eng., 129 (2000), pp. 253-255

[12]. Y. Chen, C. Lee, H. Wu, Calculation of the optimum installation angle for fixed solar-cell panels based on the genetic algorithm and the simulated-annealing method, IEEE Trans. Energy Convers., 20 (2005), pp. 467-473

[13]. H.M.S. Hussein, G.E. Ahmad, H.H. El-Ghetany, Performance evaluation of photovoltaic modules at different tilt angles and orientations, Energy Convers. Manage., 45 (2004), pp. 2441-2452

[14]. E. Calabròa, Determining optimum tilt angles of photovoltaic panels at typical north-tropical latitudes, J. Renew. Sust. Energy, 1 (2009)

[15]. C.L. Chenga, C.S.S. Jimenez, M. Lee, Research of BIPV optimal tilted angle, use of latitude concept for south orientated plans, J. Renew. Energy, 34 (2009), pp. 1644-1650

Rajveer S Dhingra, et. al. "Investigating the optimal tilt of photovoltaic solar panels in Jay Jalaram, Ahmedabad." *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)*, 16(5), (2021): pp. 52-58.