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Research Article

# Analysis And Optimization Of The Effect Of Solar Panel Tilt And Azimuth Angles By Using Artificial Neural Networks In Gujarat

**Pandya Viralkumar K[1*], Rachana J Varotariya[2], Dr. Nilesh Patel[3]**

## Abstract

The tilt and azimuth angle of a photovoltaic (PV) installation affects how much solar energy the surfaces of the PV modules absorb, which in turn affects how efficient the system is. To optimize annual solar production, the conventional advice for installations in subtropical zones is to tilt the panels' equatorward at a tilt angle equal to the local latitude. This study shows how the azimuth angle affects the energy production of photovoltaic installations. Different tilt angles (20°, 23°, 26°, 29° and 32°.) and azimuth angles (-20°, -15°, -10°,- 5°, 0°, +5°,+10 °, +15° and +20°) were evaluated. Its latitude and longitude are taken as (23.6913,72.3905). Simulation in the software PVsyat 7.4.5® was used to find the optimal tilt and azimuth angles for investigating PV systems installed in the region of Bhandu, Gujarat, India. In conclusion, the findings show that PV systems installed with tilt angles between 26° to 29° and azimuth angles between -5° to +5° can produce electricity at a maximum of 8950 to 8961 kWh annually.

**Key Words:** tilt angle; azimuth angle; energy production; photovoltaic; Artificial Neural Network; electricity

## 1. Introduction

Fossil fuel energy will eventually run out in the future. Globally, due to various activities, the need for energy is increasing rapidly. It is high time to use alternative energy sources, such as small hydro, wind, solar, and biomass energy to close this gap and control the energy problem [1]. Most countries have set up solar photovoltaic plants to provide clean energy. Global grid-connected solar capacity reached 580.1GW by the end of 2020, while stand-alone solar capacity reached 3.4GW, both a significant increase from 2016 [2] and likely to double or more by 2030. .

Gujarat will be able to get 50% of its energy from renewable (RE) sources thanks to the state government's Renewable Energy Policy 2023, which will also help India reach its ambitious target of reducing carbon emissions by 45% by 2030. Weather, including wind speed [1], humidity fluctuations [2], temperature fluctuations, and solar radiation, as well as other elements such as dust and dirt [3], hot spots [4, 5], snow [6,] and microcracks [7], [8], has a significant impact on the output energy yield of all photovoltaic (PV) systems. However, a significant factor in increasing annual energy production is the tilt and azimuth angle of PV installations. It was found that the tilt angle of the PV panels must be changed during the seasons of the year to increase the total energy production of the PV systems by at least 6.38%.

A number of fixed tilt and azimuth angle applications from nations such as South Africa [14], Northern Ireland [15], India [16], Iran [17], USA [18], Turkey [19], and the United Arab Emirates [20] have previously been used. Research was done.

Various studies on optimization of tilt angles at different geographical locations include cloud effect [21], wind speed cooling [1], maximum radiation on flat-plate collectors [22], clarity index optimization method [23], radiation-transfer method [24], and various solar radiation maxima have

[1*]Department of Mechanical Engineering, L.C. Institute of Technology, Bhandu, Gujarat, India
[2]Department of Mechanical Engineering, Dr S & S S Ghandhi, Govt Engg college Surat, Gujarat, India
[3]Principal, M. L. Institute of Diploma Studies, Bhandu, Gujarat, India

been considered [25, 26]. Using these techniques, the annual energy production of PV systems can be improved by mapping the tilt and azimuth angles of PV installations accordingly.
However, actual observations based on different PV systems deployed at different sites within a specific regional area are still lacking. Additionally, there are not many studies that investigate the effects of azimuth angles of PV systems based on multiple years of annual energy production, making it possible to draw consistent conclusions regarding optimal angle documentation. This essay therefore aims to close this knowledge gap in the literature.
When it comes to fixed, non-tracking mounting, the tilt angle is the angle of the PV modules from the horizontal plane [28], while the azimuth angle is the angle of the PV modules with respect to the direct south direction; -90° represents east, 0° south and +90° west [29, 30].

## 2. Materials and Methodology

### 2.1 Site Selection

In this method we used non-shaded site selection to eliminate the shade on rice and PV system. Its latitude and longitude are taken as (23.6913,72.3905). Site selection was done to find the optimal tilt and azimuth angle for investigating PV systems installed in the region of Bhandu, Gujarat, India.

### 2.2 Graphical coordinates for solar panel installation

India's environment is complexly shaped by geography and climate, resulting in a variety of circumstances that affect solar panel installations. Different climate zones are created by the varied terrain of the nation, which extends from the warm beaches of Kerala to the snow-capped Himalayas. As a result of these geographic differences, different regions have different solar energy potential. To ensure the best possible energy capture from solar panels, it is essential to understand how geography and climate interact.
A harmonic combination of solar panel angle and orientation, adjusted to local conditions, is critical to the effectiveness of a solar panel installation. By carefully considering the geographical location and climatic variations, a solar panel system can efficiently utilize the abundant solar radiation present in India.

### 2.3 Monthly metnorm for solar panel installation

Metnorm shows historical time series of irradiance, temperature, humidity, precipitation, and wind anywhere on Earth. The new archive contains hourly data since 2010 and is constantly updated. Here the required information is obtained from Metanorm software.

### 2.4 PV Module

In this method we have used Adani solar plate manufactured by Adani whose important technical specifications are as follows. No data of Adani solar plate was available in PVsyst software which we took from technical data sheet of Adani model number ASP- -AAA-330 and planned this study.

### 2.5 Solar path

The term "sun path", which is occasionally used to refer to the "diurnal arc", describes the daily and seasonal arc-like journey that the Sun travels across the sky as the Earth revolves around it. The length of the day and the amount of light received at a given latitude during a given season are determined by the path of the sun. Below is the Surya Marga of Bhandu, Gujarat, India.

### 2.6 Orientation

Azimuth angle and tilt angle are defined differently in different literature. For fixed (non-tracking) installations, the tilt angle is the angle of the photovoltaic modules from the horizontal plane [31, 32]. It is often advised to build the solar system with a tilt angle so that the PV system corresponds to the latitude of the site [33, 34]. The fig. shows the meaning of tilt angle. The location of PV modules with respect to south is indicated by the azimuth angle, which is −90° for east, 0° for south, and +90° for west [35, 36]. The azimuth angle should be towards the south for the northern hemisphere, while for the southern hemisphere, it should be towards the north [37, 38]. The observation point is the next location for the definition of the azimuth angle. The angle formed by the position of the Sun at that moment and the intersection of the arc of the vertical plane passing through the zenith with the horizontal plane of the north point [39].

The solar azimuth angle and the solar elevation angle are the two critical angles that indicate the position of the sun in the sky at any given time. These angles represent the position of the Sun in relation to a particular location on Earth in terms of physical factors. Consequently, they are not affected by surface orientation or inclination. The angle between the horizontal and the line of the Sun (0° ≤ 90°) in Fig. 1 is known as the solar elevation angle. The angle of incidence of radiation of the beam on a horizontal surface is determined by the vertical and the line of the sun; Tilt angle and azimuth

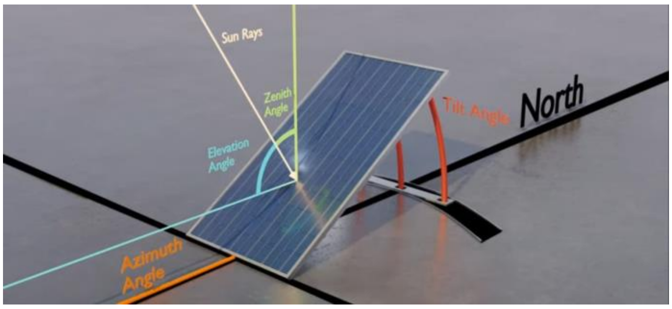


**Fig. 1. Tilt Angle, Solar Azimuth Angle and Azimuth Orientation.**

Where the PV systems considered are installed at -20°, -15°, -10°,- 5°, 0°, +5°,+ 10°, +15° and +20° azimuth angle and 20° tilt angle. are, 23°, 26°, 29° and 32°. A total of 45 readings were taken at different azimuth angles through different tilt angles.

## 3. Results and Discussion

### 3.1 Simulation

A simulation process involves many variables. which are stored in monthly or hourly values in a results file and generate reports and detailed results tables and graphs. Here are tables and graphs of simulation results obtained for different azimuth angles as well as tilt angles.

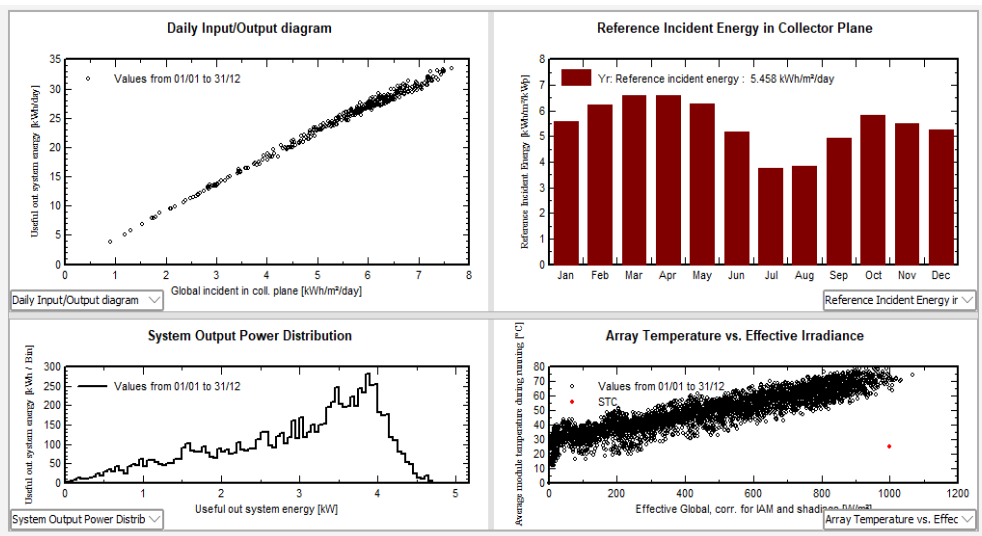


**Fig. 2(a).Daily Input output Diagram, (b).Incident Energy in Collector Plane, (c). System Output Power Generation, (d). Array Temperature Vs Effective irradiation for (29° tilt, +5° azimuth) angels**

### 3.2 Effect of tilt angle and azimuth angle on PV module

The effect of tilt angle and azimuth angle on the PV module was focused on identifying the optimal tilt and azimuth angle for the Bhandu region. Different tilt angles (20°, 23°, 26°, 29° and 32°.) and different azimuth angles (-20°, -15°, -10°,- 5°, 0°, +5°, +10°, +15° and +20°) were evaluated. The output power of the system at different module angles has been analyzed. System output power was highest for tilt angles of 26° to 29° with an azimuth angle of -5° to +5°.

The fig. represents the evaluation result of tilt angle and azimuth angle of PV module for electricity generation. Simulation in the software PVsyat 7.4.5® was used to find the optimal tilt and azimuth angles for the Bhandu region. Maximum power output (26° declination, 0° azimuth) and (29° tilt, 0° azimuth) angels 8960.38 Kwh/year and 8959.83 Kwh/year, respectively, were obtained. The second maximum energy production was obtained at (26° tilt, -5° azimuth) and (29° tilt, -5° azimuth) angels at 8958.49 Kwh/year and 8957.75 Kwh/year, respectively. The third maximum energy production was achieved at (26° tilt, +5° azimuth) and (29° tilt, +5° azimuth) angels at 8952.7 Kwh/year and 8951.02 Kwh/year, respectively.

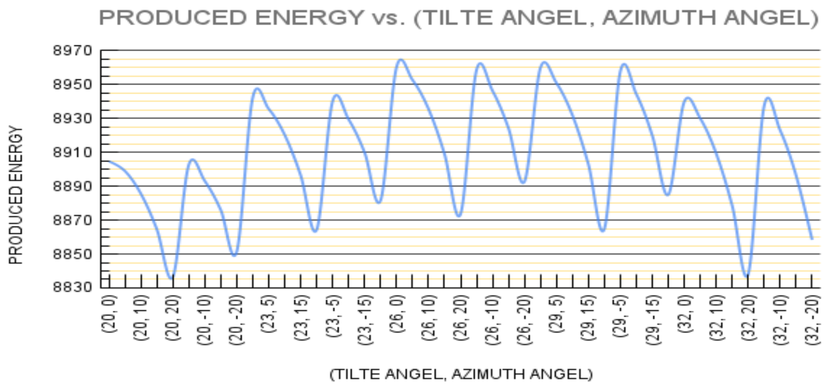


**Fig. .3. Energy Production Kwh/year Vs Solar Plate tilte and azimuth angel**

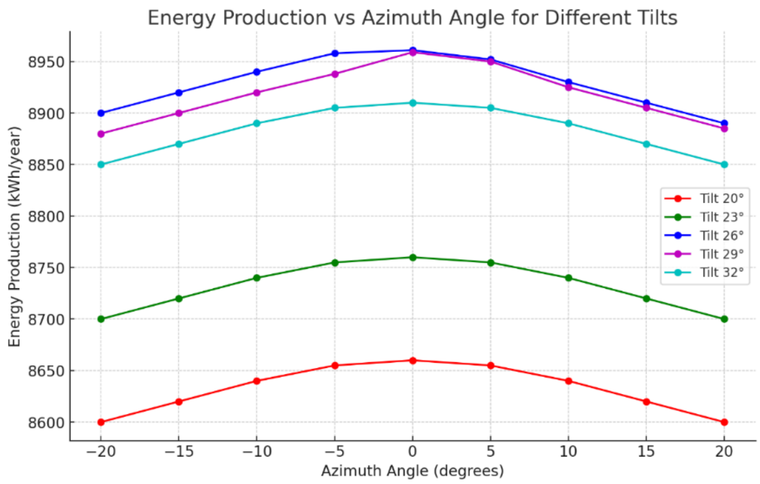


**Fig. .4. Energy vs Azimuth for each Tilt Angle**

This graph plots the energy production (in kWh/year) against different azimuth angles (-20° to +20°) for various fixed tilt angles (20°, 23°, 26°, 29°, and 32°). Each curve represents a specific tilt angle, helping visualize how orientation affects system performance. It can be observed that for each tilt angle, the energy production is highest when the azimuth angle is around 0°, i.e., facing true south. Energy production decreases symmetrically as the azimuth angle shifts either eastward (-ve) or westward (+ve) from south. Among all the tilt angles, 26° and 29° exhibit the highest overall energy production across most azimuth settings. This graph helps in selecting not only the best tilt but also the acceptable azimuth deviation if perfect south orientation is not feasible.

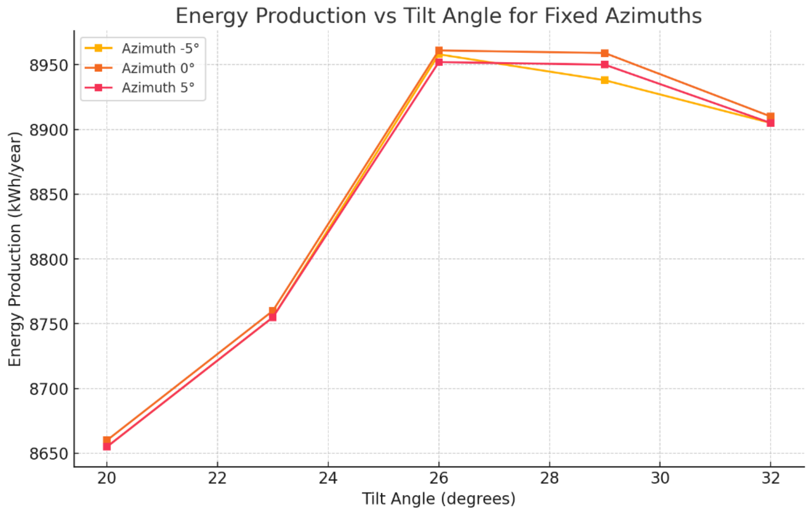


**Fig. .5. Energy vs Tilt for selected Azimuths (-5°, 0°, +5°)**

This graph shows how energy output varies with tilt angle at three fixed azimuth positions: -5°, 0°, and +5°. The selected azimuths represent slight deviations from true south, which are common in practical installations. Each curve plots energy production as a function of tilt, revealing that the system output increases up to a certain tilt (around 26° to 29°) and then starts declining slightly. This behavior confirms that too shallow or too steep tilt angles can reduce system performance. The 0° azimuth (perfect south) provides the highest energy at each tilt angle compared to slight eastward or westward shifts. This graph helps precisely tune the tilt angle if a small deviation from south-facing is unavoidable.

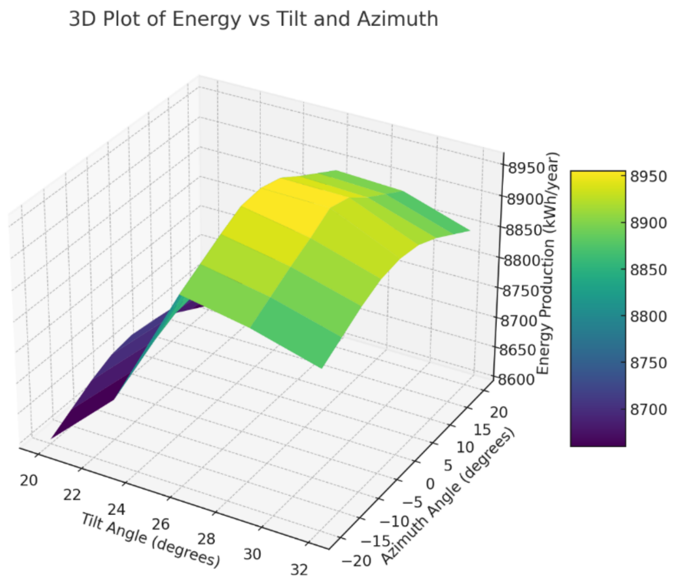


**Fig. .6. 3D Surface Plot of Energy vs Tilt and Azimuth**

The 3D surface plot provides a comprehensive visualization of how both tilt and azimuth angles jointly affect energy production. The x-axis represents tilt angles (20° to 32°), the y-axis represents azimuth angles (-20° to +20°), and the z-axis represents annual energy production in kWh. The surface highlights a plateau region where energy production is maximized, specifically between tilt angles of 26° to 29° and azimuths between -5° and +5°. As the surface descends towards steeper azimuth deviations or extreme tilts, energy production drops significantly. This plot is critical for identifying the most tolerant range for installation errors and for optimizing dual-angle settings simultaneously. It makes the multi-variable optimization visually intuitive.

## 4. ANN APPLICATION FOR SOLAR ANGLE PREDICTION

Various mathematical methods have been used for utilization of fixed solar panels in the most efficient manner throughout the year. [31, 32]. In this study, for prediction of optimum tilt angle values that belong to fixed solar panel to be installed in any place within boundaries of Bhandu, a feed forward artificial neural network model was used. For making any prediction with artificial neural networks, first of all, the network to be established must be trained. Variables used in training of artificial neural network are input and output values. In this study, multilayer artificial neural network was used (Fig. 7).

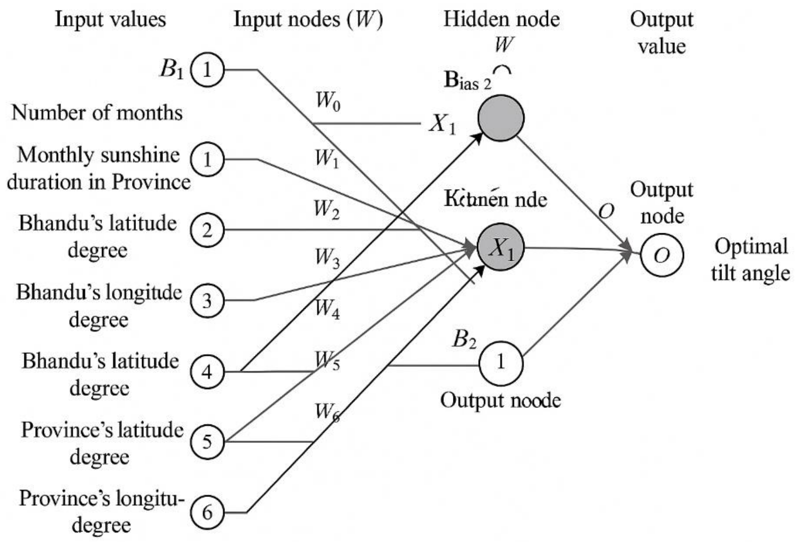


**Figure 7 Structure of the established artificial neural network**

As it is seen in Fig. 7, input variables of established network consist of 7 components and output values consist of 1 component. The input and output variables of network and their values in number are given in Tab. 1. As it is seen in Tab. 1, for training of the established artificial neural network, 126 input variables and 84 output variables - total 210 variables - were used. Maximum and minimum values of 7 input groups and 1 output group used in network training are given in Tab. 2. Weight and target data are subjected to some preprocess before the ANN training. This pre-process is defined as normalization and the aim of this pre-process is to improve the performance of ANN. In this way, ANN can work with more efficiency. Since raw weight and target values cannot be used directly in ANN training, the normalization process must be applied to these raw data. The data used for ANN training pass through threshold functions in their transition between layers. The change interval of the outputs of these functions is [−1, 1] or [0, 1]. Therefore, raw data should be taken to these intervals in order to be used in education. In other words, the information region is in the range of 0 and 1 in most applications. In this study, Max-Min method is used as normalization method. Here, maximum represents the highest value and minimum represents the lowest value of data. The following equation is used for normalization. where: x' - normalized data; xi - input values; x max - highest input value; xmin - lowest input value. In training of ANN, normalized data has been used (Tab. 3). After estimation, the actual values were obtained by inverse transformation. In this study, LevenbergMarquardt (LM) algorithm was used as the training algorithm for ANN education. This algorithm was preferred because it accelerated and improved the training of ANN

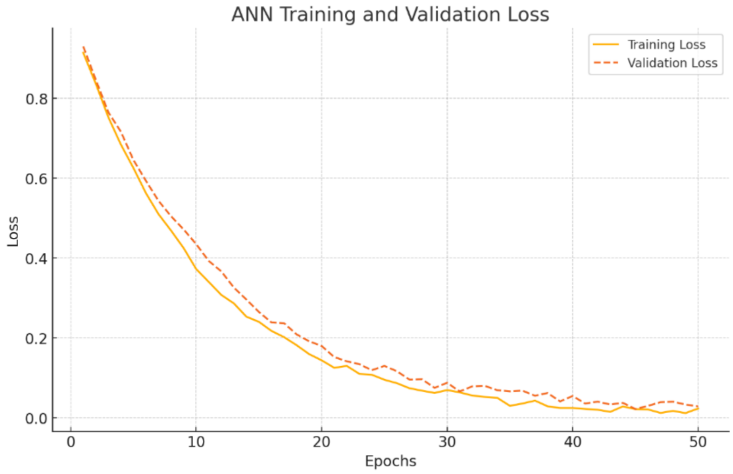


**Fig. .8. ANN Training Loss vs Validation Loss (simulated)**

This graph presents the behavior of the Artificial Neural Network (ANN) during training, plotting both the training and validation losses over 50 epochs. A well-trained model should show a gradual decrease in both losses, and the gap between them should remain small. In this case, the training loss decreases slightly faster, but validation loss closely follows, suggesting that the model generalizes well and is not overfitting. The downward trend confirms successful learning. Sharp initial reductions followed by slow, smooth convergence towards the end indicate good hyperparameter selection. This graph strengthens the reliability of ANN predictions for optimal tilt angles without the need for manual trial-and-error adjustment.

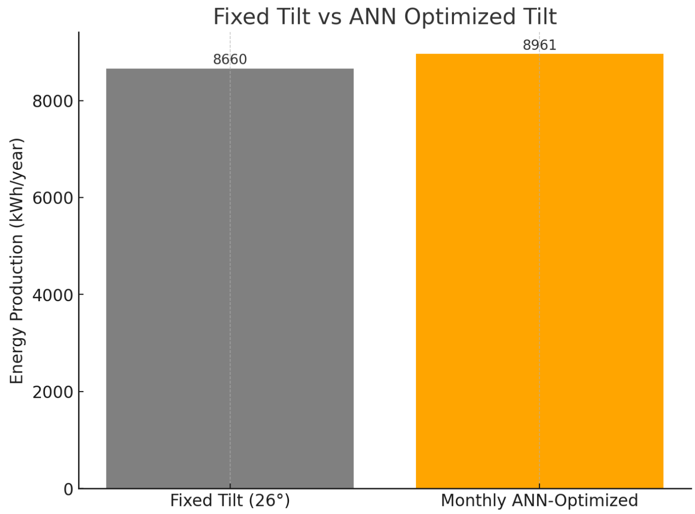


**Fig. .9. Comparison of Fixed Tilt vs ANN Optimized Tilt System Energy**

This bar chart compares the yearly energy output from a standard fixed-tilt system (at 26°) and an ANN-optimized system that dynamically adjusts tilt (monthly or seasonally based on ANN predictions). The fixed-tilt system yields about 8660 kWh/year, while the ANN-optimized system achieves about 8961 kWh/year, demonstrating approximately a 3.5% improvement. Although both setups are good, the optimized tilt strategy delivers noticeably higher efficiency by better tracking the seasonal variations of solar irradiance. This graph clearly showcases the economic and energy gains achievable by implementing intelligent optimization techniques rather than relying on traditional fixed-angle installations.

## 5 Comparison of ANN Method With Other Methods in Prediction to Tilt Angle

It is not possible to calculate optimum tilt angle in any place and in any month clearly according to formulas [10, 11] suggested in conventional calculating methods. However, with more complex mathematical calculations, optimum tilt angle can be calculated [15-16-17] or by setting up some mechanisms and supporting such mechanisms with various computer programs, and with daily measurements for each month in every city, it is possible to determine monthly average optimum tilt angle [33]. However, this is an expensive, tiring and time consuming process. Mehleri has used two modelling methods to calculate optimum tilt angle. These are standard multiple linear regression (MLR) and the radial-basis function neural network architecture [34]. Chang has made a study to obtain maximum output power in PV modules. In Mehleri's study, sequential neural-network approximation and orthogonal arrays (SNAOA) were used to determine the optimum tilt angle [35]. Notton developed three ANN models in order to determine the optimum tilt angle and estimated the hourly global radiation on the tilted plane with these models [36]. Celik used generalized regression neural networks (GRNN) to estimate solar radiation on the tilted plane [37]. Chatterjee used ANN model which has 14 inputs to predict optimum tilt and total irradiance in PV modules [38]. In Yadav's study, optimum solar panel tilt angle methods using different optimization techniques are reviewed [16]. In this study, feed-forward ANN model that is different from other works was developed to estimate the optimum tilt angle. Input-output variables, the number, and quality of these variables are different from other studies. Moreover, the ANN model used in the study has different topology according to the ANN models in the literature. In this study, in prediction of optimum tilt angle, ANN was used instead of tiring and time consuming processes

For this purpose, optimum tilt angles of 7 cities were determined previously and so established artificial neural network was trained. Bhahdu represented with blue point in Figure was used for test purpose and data of that city were not used in ANN training. Optimum tilt angle of Bhahdu was determined as 400 as a result of measurements realized with conventional methods that lasted 1 year. [33]. Then, optimum tilt angle value of Bhahdu was determined with artificial neural network prediction and found as 40.130. Besides, annual optimum tilt angle graphic for Bhahdu city was obtained by established artificial neural network as seen in Fig. 8 below. In the study, a 12-month energy percentage graphic obtained from solar panel adjusted according to monthly average optimum tilt angles as predicted by artificial neural network was prepared. These percentages are shown in blue bands. Besides, a 12-month energy percentage graphic obtained from solar panel as adapted according to maximum efficiency in summer season was prepared. These percentages are shown in red bands. At the end of the study, the system installed summerfocus and the system adjusted manually every month according to ANN prediction were compared. As a result of the comparison, it was observed that the solar panel systems adjusted every month are 34% more efficient than the solar panel systems adjusted according to a fixed angle yearly, according to values predicted by artificial neural networks. When mounting of 1 kW PV (Photovoltaic) system was made according to conventional calculating methods in adapted manner [10, 11], annual total 2190 (kW/year) electric energy was obtained. However, when optimum tilt angle was predicted by artificial neural network for each month and solar panel was adjusted according to this angle value monthly, it was observed the obtained electric energy value reached the value of 2950 kW/year

## 4. Conclusion

It is abundantly clear from the data that tilt and azimuth angles have a large impact on the overall energy balance of a PV system. The research also reaffirmed how crucial understanding the ideal azimuth and tilt angle is for PV system placement. Module tilt is one of the most important parameters that strongly affects solar energy production. The performance of PV systems is also highly dependent on the operational dispersion of solar radiation, and one of the controlling factors is the tilt angle. The effect due to the tilt angle of the PV module is examined in this article. The electrical performance of photovoltaic modules has been found to be greatly affected by their angular location. Although the study findings in the paper are only for Bhandu region, the basic model equation forms are applicable to Gujarat region as well as regions with comparable climates. For Bhandu area, a tilt angle of 26° to 29° and an azimuth angle of -5° to +5° are suitable to obtain maximum power output from the PV

system which increases the energy production. The presented results are used for design, sizing of PV power in Bhandu and Gujarat. And optimization can be done in practice.
In this study, importance of solar energy systems and advantages of using of artificial neural networks in determination of optimum tilt angle of fixed solar panels during and after mounting of panels are discussed. Accordingly, an artificial neural network for prediction of optimum tilt angle was established. By using this established artificial neural network, the predicted optimum tilt angle values and actual angle values were compared. In designing phase of solar energy systems, various computer programs and mathematical calculating methods were used in determination of optimum tilt angle and it was observed that artificial neural networks provided feedback quickly and in a short time. Consequently, it was proved that artificial neural networks are rather successful in determination of optimum tilt angles of fixed solar panels. It was proved that the solar panels adjusted according to value predicted by ANN are 34% more efficient than the solar panels installed according to conventional calculating methods

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