Optimization of Tilt Angle for Photovoltaic: Case Study Sabang-Indonesia

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Abstract. Renewable energy sources as alternative energy are needed for electrical power, reliability such as Sabang tourism area. This paper provides the most optimal angle of installation of photovoltaic (PV) to obtain the optimum PV energy with the genetic algorithm method. Daily energy that PV can accept as fitness, the tilt angle (β) as an individual evaluation with a limit of -90° to 90°. The optimal tilt angle in the area of the simulation results is equal to 6° facing south. Comparisons are made with tilt angles of 15, 30, and 60° facing south. The results show that installation with an optimal angle with the genetic algorithm method can increase the energy received by PV by 2%, 9.5%, and 38%.

1. Introduction
Sabang is one of the coastal tourism areas in Indonesia. With the potential for solar intensity reaching 4.5 kWh / m2 / day it is very feasible to use Photovoltaic (PV) power generation as a renewable energy source. For optimal design of PV, it is necessary to calculate its effective placement with a fixed angle and direction.

The energy received by PV is influenced by the direction and tilt angle of PV to latitude because the changes in the direction of latitude and north-south direction are from 23° 0.26' north latitude to 23° 0.26' south latitude. So, the area within this range changing path to the north-south every year.

Some research has been done to this suggestion: A mathematical model was used for estimating the total solar radiation on a tilted surface, and to determine the optimum tilt angle and orientation for the solar collector in India in four different locations on a monthly basis, as well as for a specific period. The results reveal that changing the tilt angle 12 times in a year maintains approximately the total amount of solar radiation near the maximum value that is found by changing the tilt angle daily to its optimum value. A numerical approach was used to calculate the solar radiation on sloped planes by integrating the measured sky radiance distributions [1]. The annual total solar yield at different sloped surfaces facing various orientations and monthly solar radiations at the optimal tilt surface and three vertical planes facing east, south, and west were determined. For Tunisia [2] the PV panel was rotated towards the east, south and west and positioned for the angles 0°, 30°, 45°, 60° and 90°.

The technique to solve optimization problems can use heuristic global optimization methods. The use of heuristic methods have been widely used to solve optimization problems, such as Genetic Algorithm (GA) [3].

In this paper, the proposed method of genetic algorithms to optimize the direction and the angle of installation of solar panels in Sabang-Indonesia. Encoding of chromosomes using real coding with the
fitness function involving direct radiation, radiation diffuse and radiation reflected obtain the total average daily solar radiation on the surface of the incline (HT) which can be accepted solar panels.

2. The Proposed Method/Algorithm

2.1. Solar Radiation

Total average daily solar radiation received by a tilted surface (HT) which can be received by the solar panels is calculated using a mathematical model estimates the potential of solar energy and the ability of solar technology [9][3][10][11] is to consider the direct radiation (HB), radiation diffuse (HD) and the reflected radiation (HR). where,

\[ H_T = H_B + H_D + H_R \]  

(1)

where \( H_B \) is a direct daily radiation received on an inclined surface (KWH / m\(^2\)-day) can be expressed as:

\[ H_B = \left( H_g - H_d \right) \frac{\cos(\theta)}{\cos(\theta_2)} \]  

(2)

where:

- \( H_g \): Average global radiation Monthly on the horizontal surface of the earth (kWh / m\(^2\)/d)
- \( H_d \): Average radiation diffuses monthly on the horizontal surface of the earth (kWh / m\(^2\)/d)
- \( \theta_2 \): zenith angle(o)
- \( \theta \): angle of incidence(o)

Figure 1 shows the declination angle, i.e. changes in the sun's path in a year towards latitude (north-south) from 23 ° 0.26 'north latitude to 23 ° 0.26' south latitude.

![Figure 1: Declination Angle](image)

The angle of incidence using the equation [9]:

\[
\cos(\theta) = \sin(\delta)\sin(\varphi)\cos(\beta) - \sin(\delta)\cos(\varphi)\sin(\beta)\cos(\gamma) + \cos(\delta)\cos(\varphi)\cos(\beta)\cos(\omega) + \cos(\delta)\sin(\varphi)\sin(\beta)\cos(\gamma)\cos(\omega) + \cos(\delta)\sin(\beta)\sin(\varphi)\sin(\omega)
\]

(3)
zenith angle using the following equation:

$$\cos \theta_z = \cos(\varphi) \cos(\delta) \cos(\omega) + \sin(\varphi) \sin(\delta)$$  \hspace{1cm} (4)

where:

- \(\varphi\): latitude (°)
- \(\delta\): solar declination (°)
- \(\omega\): hour angle (°)
- \(\beta\): the angle of the panel (°)
- \(\gamma\): surface azimuth angle (°)

Solar declination based on the following equation.

$$\delta = 23.45^\circ \sin \left(360^\circ \frac{284 + n}{365}\right)$$  \hspace{1cm} (5)

\(H_D\) is calculated by:

$$H_D = (H_B \rho) \left(1 - \cos(\beta)\right)^2$$  \hspace{1cm} (6)

where:

- \(\rho\): ground albedo

\(H_R\) radiation reflected is calculated by:

$$H_R = H_D R_d$$  \hspace{1cm} (7)

where \(R_d\) is a comparison of the daily diffuse radiation at an oblique angle to the horizontal surface.

$$R_d = \frac{3 + \cos(2\beta)}{4}$$  \hspace{1cm} (8)

2.2. The Objective

The purpose of this study is to maximize the energy received by the panel by calculating the most optimal angle of PV from various changes in declination angle in one year. Thus, the objective function based on the total radiation intensity received by PV can be calculated as:

$$Fitness = \sum_{i=1}^{n_{max}} H_B + H_D + H_R$$  \hspace{1cm} (10)

2.3. Proposed Algorithm

The detail of the proposed algorithm are as follows:

1. Generating an initial population.
2. Decodes variable tilt angle of the solar panels (\(\beta\)) with the limits defined.
3. \(x_i = x_{min} + (x_{max} - x_{min}) \text{ chromosomes}\)
4. Evaluation of individual to find the best fitness
5. The selection process by the method of selection tournament, elitism, crossover and mutation.
6. Repeat steps 4-5 until the maximum generation.
7. Show total daily radiation, and the angle of the solar panel.

3. Results and Analysis
The study was conducted to determine the tilt angle of the solar panel installation in Sabang Aceh as shown in Figure 2.

![Figure 2. Sabang Island (5.8 N, 95.3 E)](image)

Optimization of the optimum annual tilt angle simulation results shown in Figure 3. The fixed angle of the PV is 6° facing south. Table 1 shows the energy that can be received after the optimization of the annual panel angle. The total energy received by PV with an optimum tilt angle throughout the year is 1.86MWh/m²/year.

![Figure 3. The optimal angle of the solar panel annual](image)

Table 1 shows the comparison of the energy received by PV between the optimal tilt angle proposed with several different angles. Comparisons are made with tilt angles of 15°, 30°, and 60° facing south. Then a comparison is also made with a tilt angle of 15° and 30° degrees north facing.

**Table 1.** Energy received by PV with several different slope angles
The average annual energy comparison chart acceptable to PV is shown in Figure 4. The average increase in energy received by PV with an optimal slope angle (6 deg) compared to a slope of 15 deg is 32 kW / m² / year or 2%. The increase in energy received by PV compared to the slope angle of 30 deg is 177 kW / m² / year or 9.5%. And the improvement compared to the slope angle of 60 deg is 707 kW / m² / year or 38%.

Figure 4. Average annual energy received by PV

| Angle of solar panels (β) | Energy (kWH/m²/year) |
|--------------------------|-----------------------|
| 6                        | 1865                  |
| 15                       | 1833                  |
| 30                       | 1688                  |
| 60                       | 1158                  |
| -15                      | 1769                  |
| -30                      | 1565                  |

4. Conclusion
In this paper, the genetic algorithm method is proposed to obtain the optimum tilt angle of the Photovoltaic annual periods for installation in Sabang, Indonesia. Simulation optimization tilt angle that has been done and it can be concluded that: Optimization of the annual period obtained from simulations using genetic algorithms obtained PV’s tilt angle is 6 degrees facing south. The results showed that the installation with an optimal angle using genetic algorithm method could increase the energy received by PV to 38%.

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References
[1] D. H. W. Li and T. N. T. Lam, “Determining the optimum tilt angle and orientation for solar energy collection based on measured solar radiance data,” *Int. J. Photoenergy*, vol. 2007, 2007.

[2] H. Tlijani*, 1, 1, and R. B. Y. 3, Abir Aissaoui 2, “Optimization of tilt angle for solar panel: Case study Tunisia,” *Indones. J. Electr. Eng. Comput. Sci.*, vol. 8, no. 3, pp. 762–769, 2017.

[3] A. Nawabjan, F. Iqbal, and A. S. Abdullah, “A Front Surface Optimization Study for Photovoltaic Application,” vol. 16, no. 4, pp. 1383–1387, 2018.

[4] H. Sharma, N. Pal, and P. K. Sadhu, “Modeling and Simulation of Off-Grid Power Generation System Using Photovoltaic,” *TELKOMNIKA Indones. J. Electr. Eng.*, vol. 13, no. 3, pp. 418–424, 2015.

[5] M. Musaruddin, A, U. Rianse, B, and Aditya Rachman, “Halu Oleo University Indonesia towards the green campus through the application of solar energy to support the electricity generation,” *Int. J. Smart Grid Clean Energy*, vol. 4, no. 2, pp. 151–158, 2015.

[6] M. Benghanem, “Optimization of tilt angle for solar panel: Case study for Madinah, Saudi Arabia,” *Appl. Energy*, vol. 88, no. 4, pp. 1427–1433, 2011.

[7] A. Agarwal, V. K. Vashishtha, and S. N. Mishra, “Comparative Approach For The Optimization Of Tilt Angle To Receive Maximum Radiation,” vol. 1, no. 5, pp. 1–9, 2012.

[8] A. Soeprijanto, O. Penangsang, U. Khairun, and U. N. Makassar, “Optimal Expenditure and Benefit Cost Based Location , Size and Type of DGs in Microgrids Systems Using Adaptive Real Coded Genetic Algorithm,” vol. 16, no. 1, pp. 10–17, 2018.

[9] J. A. Duffie and W. A. Beckman, *Solar Engineering of Thermal Processes Solar Engineering*. 2013.

[10] A. Rachman, U. Rianse, M. Musaruddin, and K. Ornam, “Technical, economical and environmental assessments of the solar photovoltaic technology in Southeast Sulawesi, a developing province in Eastern Indonesia,” *Int. J. Energy Econ. Policy*, vol. 5, no. 4, pp. 918–925, 2015.

[11] Y. Riffonneau, S. Bacha, F. Barruel, and S. Ploix, “Optimal Power Flow Management for Grid Connected PV Systems With Batteries,” *IEEE Trans. Sustain. Energy*, vol. 2, no. 3, pp. 309–320, 2011.

[12] Y. Asnawi, “Voltage Constrained Optimal Power Flow Based Using Genetic Algorithm,” vol. 27, pp. 9–14, 2015.