Genetic Algorithm as a Solutions Optimization of Tilt Angles for Monthly Periods of Photovoltaic Installation

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Abstract. Changes in the sun's declination angle, every month for one year affect the energy received by a photovoltaic (PV). Changing the tilt angle, every month to follow changes in sun declination needs to be done so that the energy produced by PV is more optimum. Genetic algorithm (GA) was proposed in this study as the optimal PV slope solution every month of the year. GA calculates the slope angle of PV by calculating changes in sun declination, the movement of the sun from east to west, the coordinates of the location of PV installation, direct radiation and diffuse radiation. GA initializes tilt angle PV with the specified limit, then calculates to get the optimum total energy value on the inclined plane that PV can accept with the crossover, mutation and selection process. Algorithms are limited to 50 generations. The results showed that the optimization of the monthly period slope was better than the annual period. Installation with a slope angle after the monthly period optimization has increased the energy received by solar panels by 12 kWh/m²-year compared to installations with the slope of the annual period of optimization.

1. Introduction
Declination is the angular distance of the sun north or south of the earth's equator. The earth's equator is tilted 23.45 degrees with respect to the plane of the earth's orbit around the sun, so at various times during the year, as the earth orbits the sun, declination varies from 23.45 degrees north to 23.45 degrees south [1].

This gives rise to the seasons. Around December 21, the northern hemisphere of the earth is tilted 23.45 degrees away from the sun, which is the winter solstice for the northern hemisphere and the summer solstice for the southern hemisphere. Around June 21, the southern hemisphere is tilted 23.45 degrees away from the sun, which is the summer solstice for the northern hemisphere and winter solstice for the southern hemisphere. On March 21 and September 21 are the fall and spring equinoxes when the sun is passing directly over the equator.

Changes in the sun's declination angle, every month for one year affect the energy received by a photovoltaic (PV). Changing the tilt angle, every month to follow changes in sun declination needs to be done so that the energy produced by PV is more optimum.

Some research has been done to this suggestion: A mathematical model was used for determining 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 [2]. 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 Madinah, the study is based on the measured values of daily global and diffuse solar radiation on a horizontal surface [3] °.
Genetic Algorithm (GA) was used to solve optimization tilt angle annual periods of PV installation. Installation at an angle after the optimization of the energy received increased solar panels to 9% Compared with tilt 20° direction to the north without optimization. And an Increase of 8.9% Compared with tilt 30° direction to the south without optimization. As well as an Increase of 65.5% Compared with the installation of a 90° direction to the south[4].

In this paper, the proposed method of genetic algorithms to optimize the direction and the angle of installation of PV for monthly periods in Lhokseumawe 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 [5][6][7][8] is to consider the direct radiation (HB), radiation diffuse (HD) and the reflected radiation (HR). where,

\[ HT = HB + HD + HR \]  \hspace{1cm} (1)

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

\[ HB = (Hg - HD) \frac{\cos(\theta)}{\cos(\theta_\text{z})} \]  \hspace{1cm} (2)

where:

- \( Hg \) : Average global radiation monthly on the horizontal surface of the earth (kWh / m\(^2\)/d)
- \( HD \) : Average radiation diffuses monthly on the horizontal surface of the earth (kWh / m\(^2\)/d)
- \( \theta_\text{z} \) : zenith angle(o)
- \( \theta \) : angle of incidence(o)

Figure 1 shows the declination angle, ie 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.

The angle of incidence using the equation [9]:

\[
\cos(\theta) = \sin(\delta)\sin(\phi)\cos(\beta) - \sin(\delta)\cos(\phi)\sin(\beta)\cos(\gamma) + \cos(\delta)\cos(\phi)\cos(\beta)\cos(\omega) + \cos(\delta)\sin(\phi)\sin(\beta)\cos(\gamma)\cos(\omega) + \cos(\delta)\sin(\beta)\sin(\gamma)\sin(\omega)
\]  \hspace{1cm} (3)

zenith angle using the following equation:
\[
\cos \theta_z = \cos(\varphi) \cos(\delta) \cos(\omega) + \sin(\varphi) \sin(\delta)
\]

(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.

\[
\delta = 23.45 \sin(360^\circ \frac{284 + n}{365})
\]

(5)

\( H_D \) is calculated by:

\[
H_D = (H_B \rho) \frac{(1-\cos(\beta))}{2}
\]

(6)

where:

\( \rho \): ground albedo

\( H_R \) radiation reflected is calculated by:

\[
H_R = H_d R_d
\]

(7)

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

\[
R_d = \frac{3+\cos(2\beta)}{4}
\]

(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:

\[
Fitness = \sum_{i=1}^{n_{\text{max}}} H_B + H_D + H_R
\]

(10)

2.3 **Proposed Algorithm**

The detail of the proposed algorithm are as follows:

1. Generating the initial population.
2. Decodes variable tilt angle of the solar panels (\( \beta \)) with the limits defined.
3. \( x_i = x_{\text{min}} + (x_{\text{max}} - x_{\text{min}}) \) chromosomes
4. Evaluation of individual to find the best fitness by calculating changes in sun declination, the movement of the sun from east to west, the coordinates of the location of PV installation, direct radiation and diffuse radiation

\[
Fitness = \sum_{i=1}^{n_{\text{max}}} H_B + H_D + H_R
\]

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 daily radiation every month, and the tilt angle monthly periods of the PV.
3. Results and Analysis

The study was conducted to determine the angle of the solar panel installation in Aceh (05° 18’ N and 97° 14’ E) as shown in Figure 2.

![Figure 2. Lhokseumawe-Indonesia (05° 18’ N and 97° 14’ E).](image)

1. The tilt angle panel before optimization

Simulations to determine the acceptable solar energy panels on a random tilt angle is done with an angle of 20° to the north, 30° to the south and 90 to the south. Table 1 shows the simulation results prior to optimization of the angle of the solar panel. The simulation was performed to determine the acceptable energy panel with several tilt angles of the solar panel.

| Month     | Solar Radiation Received (kWh/m²-day) | The angle of solar panels (β) |
|-----------|--------------------------------------|------------------------------|
|           |                                       | β = -20 | β = 30 | β = 90 |
| January   | 4.200 | 5.203 | 2.684 |
| February  | 5.378 | 6.199 | 2.592 |
| March     | 5.567 | 5.611 | 1.733 |
| April     | 4.672 | 4.158 | 1.022 |
| May       | 3.619 | 3.046 | 0.815 |
| June      | 3.395 | 2.789 | 0.718 |
| July      | 3.607 | 2.974 | 0.716 |
| August    | 3.715 | 3.243 | 0.967 |
| September | 3.722 | 3.527 | 1.337 |
| October   | 3.675 | 3.841 | 1.719 |
| November  | 3.361 | 3.826 | 1.981 |
| December  | 3.204 | 3.808 | 2.095 |
| Average   | 4.010 | 4.019 | 1.532 |

**Table 1. The angle of the panel before optimization**

Energy/year (kWh/m²-year) | 1460 | 1466 | 559
2. Monthly angle optimal panel

Simulation to obtain optimal tilt angle panels monthly and the early period was conducted using a genetic algorithm (AG). Limits used the angle of inclination 90° to the south and 90° to the north with the consideration declination of the sun moving in one year amounted to 23.45° to the north and 23.45° to the south. The simulation was performed with 12 variables, 100 population and 50 generations.

The Monthly optimal tilt angle of the panel with an acceptable energy panel are shown in Table 2. In the January to March, the optimal tilt angle of 5° - 23° facing south. April to May and August to September with an optimal tilt angle of 2° facing south until 2° facing north. In June and July, the optimal tilt angle of 8° facing north. While in November and December, the optimal tilt angle is 10° - 22° facing south.

| Month     | Tilt Angle (deg) | Solar Radiation Received (kWh/m²-day) |
|-----------|------------------|--------------------------------------|
| January   | 5 to 23          | 5.281                                |
| February  |                  | 6.361                                |
| March     |                  | 6.134                                |
| April     | (-) 2 -2         | 4.879                                |
| May       |                  | 3.715                                |
| June      | (-) 8            | 3.470                                |
| July      |                  | 3.689                                |
| August    | (-) 2 -2         | 3.857                                |
| September | 10 to 22         | 3.981                                |
| October   |                  | 4.118                                |
| November  |                  | 3.940                                |
| December  |                  | 3.910                                |

Comparison of energy that solar panels can be received average monthly periods optimization is shown in Figure 3. In the tilt angle before optimization with an angle of 20° facing north obtained an average daily energy panel that is acceptable is 4.01 kWh/m²-day with total annual energy is 1460 kWh/m². Installation of solar panels with an inclination of 30° facing south will produce an acceptable energy panel is equal to 1550 kWh/m²-year. And installation of panels at an angle of 90° facing south, solar energy panels that can be accepted is equal to 559 kWh/m²-year.

After optimizing the angle of the panels, of the monthly period, the average daily energy received by the solar panel is 4.44 kWh/m²-day, with total energy per year is 1622 kWh/m²-year. The simulation results before and after the optimization of the inclination angle of the solar panels of the monthly period indicate an acceptable solar energy increase. For monthly optimization, the energy increases of 132 kWh/m2-yr compared to the 20° angle north-facing and the energy increases of 72 kWh/m2-year compared to the 30° angles facing south.
Figure 3. Comparison of Energy daily average solar panel that can be accepted between the corners without optimization with monthly optimization angle

From Figure 4 shows the installation of the monthly period of the slope angle, the energy that can be received by PV increases by 12 kWh / m2-year compared to the optimization of the annual period slope angle.

Figure 4. Comparison of Energy daily average solar panel that can be accepted between the angle optimization annual periods with monthly periods of angle optimization.

4. Conclusion

Optimization of the angle of the solar panel proposed show better results than the mounting panel without optimizations that can increase the energy that can be accepted by the panel 8-65%. A Monthly optimal tilt angle of the panel in January to March, the optimum tilt angle of 5° - 23° facing south. April to May and August to September with the optimal tilt angle of 2° facing south until 20° facing north. In June and July, the optimum tilt angle of 8° facing south. While in November and December, the optimum tilt angle is 10° - 22° facing south.
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