

Comparison of PV System Energy Output Between with and without Solar Tracking: Simulation in a Mountain Area in Indonesia

Elieser Tarigan

*Departement of Electrical Engineering, and
PuSLET Universitas Surabaya*

Surabaya Indonesia

elieser@staff.ubaya.ac.id

Abstract— One of the key performances of a PV system is the amount of solar irradiation received by PV modules. Solar irradiation will be maximum received by solar modules when the angle of incidence is kept 0° using a solar tracker system. This paper studies comparison of the energy output of PV systems between with and without solar tracking in a mountain area of Bromo, Pasuruan, East Java, Indonesia. The studies are carried out using SolarGIS PV Planner simulation. It found that specific energy output PV system with two axes solar tracking system is 2060 kWh/kWp per year, while for the system without solar tracking (fixed optimized), the specific energy production is 1657 kWh/kWp.

Keywords—PV system, solar tracking, photovoltaic, specific energy output

I. INTRODUCTION

The use of fossil-based energy, which the source of world energy until today, has been generally recognized as one of the most impact in greenhouse gas emissions that contributes to the global climate change [1]. On the other hand the fossil energy resources such as oil, gas, and coal are limited and depleted [2]–[4]. To ensure the sustainability of energy, we should attempt to find alternative energy sources. Solar energy using photovoltaic (PV) technology is one of the promising energy resources that can be exploited. Solar energy is abundantly available in the form of light or radiation and technologically can be converted into electricity using a photovoltaic (PV) system.

The Government of Indonesia recently published the General National Energy Plan (Rencana Umum Energy Nasional, RUEN), through the Ministry of Energy and Mineral Resources (MEMR). In the RUEN 23% of national energy demand is planned to be supplied by renewable energy by 2025 [5]. Solar (PV) system is projected to produce power about 6.5 GW by 2025, as a part of 45 GW of total renewable energy power to be generated. [5]–[7].

The amount of electrical energy generated by a PV system depends on various factors, including material properties and operational conditions of the PV. For the

latest factor, one of the most important factors is the amount of solar irradiance received by PV modules to be converted into electricity. The solar irradiance consists of direct, diffuse, and reflected irradiation components—the sum of the three components called global irradiation [8]. For the direct component, the amount of irradiation depends on the angle of incidence. As the Sun moves continuously, the angle of incidence for a fixed surface would change over time. The angle of incidence is formulated with Eq.1 [8].

$$\cos \theta = (\sin \delta \sin \phi \cos \beta - \sin \delta \cos \phi \sin \beta \cos \gamma + (\cos \delta \cos \phi \cos \beta + \cos \delta \sin \phi \sin \beta \cos \gamma) \cos \omega + (\cos \delta \sin \beta \sin \gamma) \sin \omega \quad (1)$$

where θ is angle of incidence, δ is the angle of declination, ϕ is the angle of latitude, β is the angle of tilt, γ is azimuth angle, ω is hour angle.

Solar irradiation will be maximum received by solar modules when they are exposed and facing directly or perpendicularly to the Sun all the time. In terms of Eq. 1, the angle of incidence should be kept at 0° . Technically, it would be possible to employ the solar tracker system. On the other hand, the solar tracking system would require additional equipment, which means additional cost for the system. It would be interesting and important to figure out the comparison energy production of the PV system between with and without solar tracking in a particular area.

The potential of solar irradiation is different from place to place around the earth. It is important to make an assessment study of the solar radiation potential, as well as its characteristics in a particular place, before installing the real PV system there. The common assessment study is done by simulation. There were quite many studies, and simulations of solar assessment in many different countries worldwide were found in the literature [9]–[14]. However, limited studies could be found for the Indonesian situation, especially for mountain areas [15], [16].

This paper studies comparison of energy output of pv system between with and without solar tracking in mountain area of Bromo, Pasuruan, East Java, Indonesia.

The area is a rural place where most of the area still unelectrified by the national grid of Indonesia (Perusahaan Listrik Negara, PLN). The studies are carried out using computer simulation using SolarGIS Pvplanner [17], [18]. The objective of the study is to compare and figure out the specific energy output between the optimized fixed tilted installation of PV system (without tracking system) with the one system that solar tracking system is applied. It is expected that the information found will be a useful reference application, development, and promoting solar energy in Indonesia

$$\text{Specific Energy Output} = \frac{E_{out, AC}}{P_{max, STC}} \quad (2)$$

where $E_{out, AC}$ is energy output for the actual condition; $P_{max, STC}$ is power capacity under standard test conditions. The specific energy production of two different simulated conditions is discussed and presented in this paper.

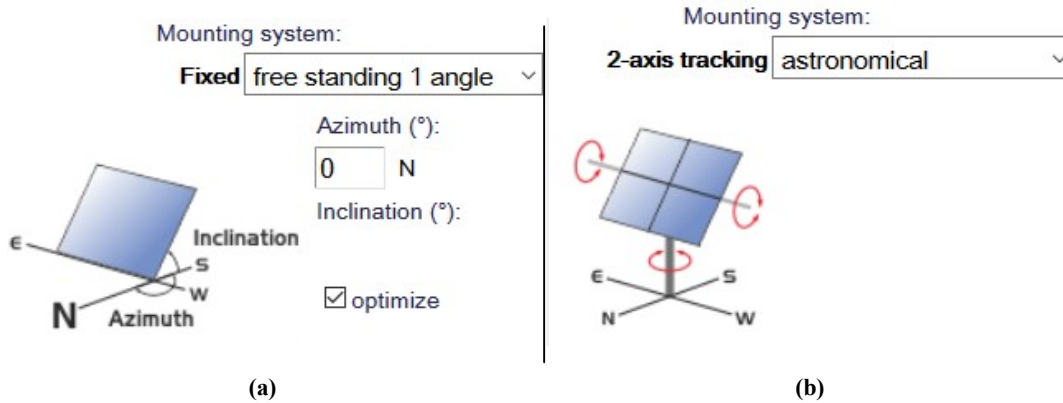


Fig. 1. Schematic diagram of PV mounting: (a) fixed free standing 1 angle ; (b) 2-axis tracking

II. METHODS

Simulation is conducted out using SolarGIS Pvplanner [18]. The software applies online numerical simulation for the input parameters and climate databases. The climate databases for the specific area, such as the solar insolation, is interpolated from the real measurement data of the closest weather station. The simulated area was located in Bromo mountain, Pasuruan East Java, Indonesia. The detail of the geographical data of the location is presented in Table 1.

The capacity of the PV system simulated is 1000 Wp, with a grid-connected installation system. The other input parameters are shown in Table 1. Two different mountings of PV systems were simulated: (1) without a tracking system, i.e. fixed free-standing one axis one angle with optimized angles. According to the geographical position, the optimum tilt is 12° from the horizontal with panel azimuth is 0° or facing to North; (2) with the tracking system, i.e., two-axis tracking system. Schematically, the two different mounting systems is presented in Fig.1. The specific energy output of a PV system is the amount of energy output in comparison with the input solar irradiation under operating conditions. It is calculated by comparing PV system energy output E_{out} , in kWh to maximum power capacity, P_{max} , in kWp under STC. Therefore the unit of the specific energy output is kWh/kWp. Mathematically it be expressed as:

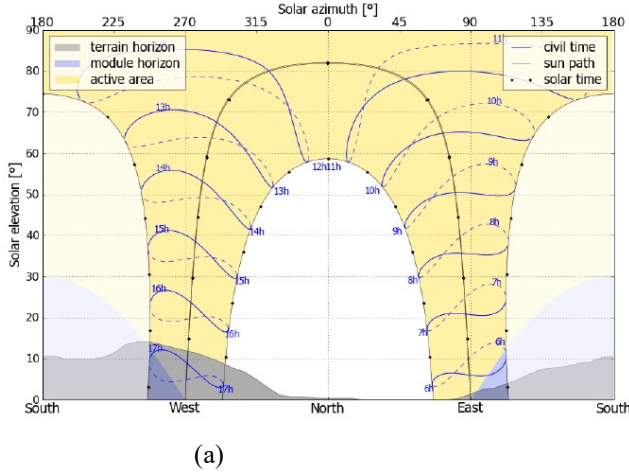
TABEL 1. INPUT PARAMETERS FOR SIMULATION

Parameters	Input
Geographical coordinates	07° 52' 57.66" S, 113° 03' 2.48" E
Time zone	UTC+07
Terrain Elevation	3 m
PV module type	c-Si - crystalline silicon (mono or polycrystalline)
Inverter type	String inverter
Transformer type	Standard transformer
Snow and soiling losses at PV modules	Monthly soiling losses up to 3.5% · Monthly snow losses up to 0.0%
Cabling losses	DC cabling 1.0% ; DC mismatch 0.5% ; AC cabling 0.4%
System availability	98.0%

III. RESULTS AND DISCUSSIONS

A. Solar Energy Potential

The availability of solar energy at the specific location is needed to assess such as solar irradiation, radiation components, day length, sun path, and temperature, etc.



about 6.21 Wh/m^2 per hour during 12:00 – 13:00 in August.

In comparison, less solar irradiation happens during December, January, and February, and March. It is probably due to these periods were the rainy season. The lowest irradiation was found during January, with a daily

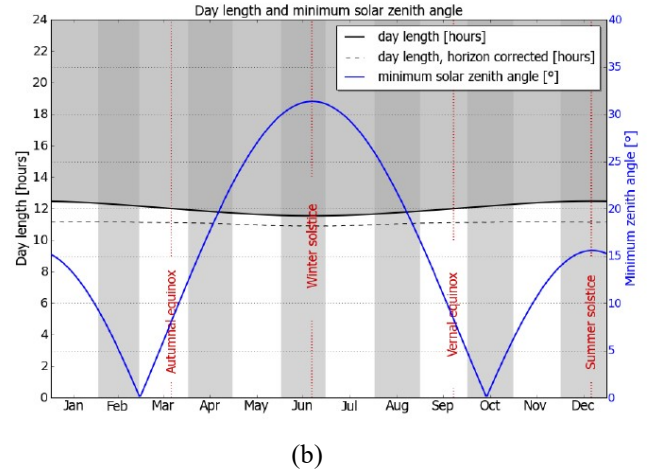


Fig. 2. Sun path (a); and Solar zenith angle and day length (b) over a year in Bromo

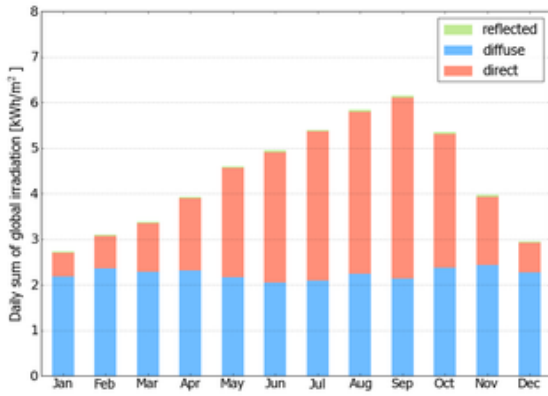


Fig. 3. Global irradiation in Bromo

Fig. 2 (a) shows the annual Sun path in Bromo. The sun path indicates the active area with solar and civil time, terrain horizon, and module horizon. The day length variation and solar zenith angle in Bromo over a year are shown in Fig. 2 (b). Any obstructed objects by a higher terrain horizon would cause a shorter period of the Sun is above the horizon in comparison to the astronomical day length.

The daily average of global irradiation, which consists of direct, diffuse, and reflected components in Bromo is shown in Fig.3. It is found that throughout the year, solar irradiation in Bromo is dominated by diffuse components, followed by direct components. The reflected component was found very small fraction. It was found that the relatively high solar irradiation happens during June – November. The highest value of global solar irradiation is

average of 3.57 kWh/m^2 . The annual solar irradiation in Bromo is found about 1625 kWh/m^2 per day with a daily average of 4.45 kWh/m^2 . This number is quietly closed to other areas in Indonesia that have been previously reported [19], [20]. The daily ambient temperature in Bromo ranges from 22°C to 23°C .

B. Comparison of Specific Energy Output

The monthly comparison of specific energy output between fixed optimized mounting and solar tracking systems is presented in Fig. 4. Both systems produce the highest electrical energy during the month of September, and the lowest energy during January. The the mothly specific energy output of the fixed mounted system ranges from 75.2 kWh/kWp to 147.1 kWh/k , while for the system with solar tracking the monthly specific energy output

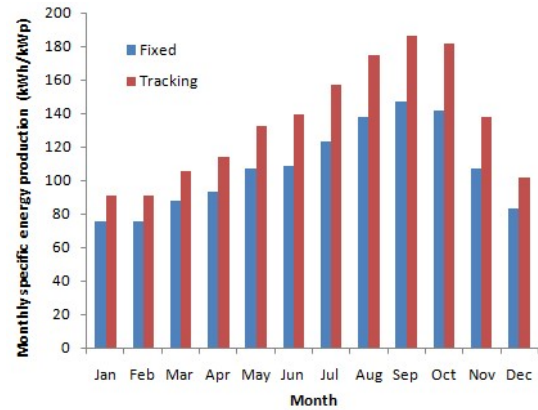


Fig. 4. Comparison of montly specific energy energy output

ranges from 90.9 kWh/kWp to 196.4 kWh/kWp. The detail monthly comparison of the energy-specific energy output by both system is shown in Fig. 4.

The monthly specific energy output is closely related to the daily average specific energy output, as shown in Fig. 5.

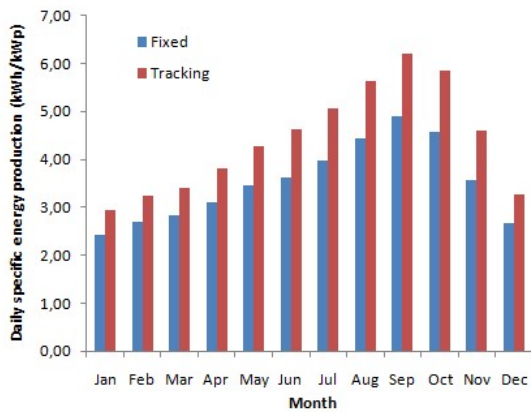


Fig. 5. Comparison daily specific energy energy outpt

It is obviously seen that the PV system with solar tracking system produces higher energy each month throughout the year. The difference of specific energy output ranges from 20% – 29 %, where the system with solar tracking always produces higher energy. The comparison of energy output in terms of monthly percentage is presented in Fig. 6.

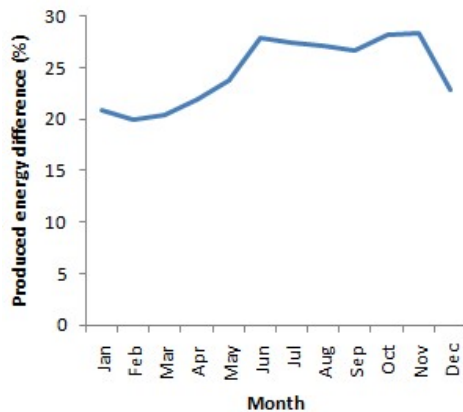


Fig. 6. The difference energy in percentage

Annually, the specific energy output for three different conditions is summarised in Table 2. It can be concluded that employing a solar tracking system for PV systems in Bromo would produce energy about 24% higher than with the conventional fixed installation.

TABEL 2. ANNUAL ENERGY PRODUCTION BY THE DIFFERENT MOUNTING OF PV SYSTEM

Mounting	Annual energy [kWh/m ²]	Relative to optimally inclined [%]
Horizontal	1625	98.1
Optimally inclined (12°)	1657	100
2-axis tracking	2060	124.3

IV. CONCLUSIONS

Simulations of the comparison of PV system energy output between with and without solar tracking system in Bromo, the mountain area of East Java, Indonesia, have been carried out. It is found that the difference of specific energy output ranges from 20% – 29 %, where the system with solar tracking always produces higher energy throughout the year. Annual specific energy with solar tracking system is about 2060 kWh/kWp, while the system without tacking system (fixed mounting) is about 1657 kWh/kWp. It means that the solar tracking PV system in the simulated place is about 24% higher than with the conventional fixed installation.

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