Effect of peak sun hour on energy productivity of solar photovoltaic power system

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ABSTRACT

A solar cell is a type of renewable energy engineering technology that can convert photons coming from the sun to be converted into electrical energy. The amount of energy that can be converted by a solar cell is determined by the effective insolation time. Peak sun hours (PSH) are the focus of this research. This PSH analysis aims to determine the potential for solar energy obtained in geographical locations throughout the year. Geographical location and the position of the astronomical coordinates of a certain area affect PSH. Therefore, the orientation of solar panel installation, including the height, slope, and latitude of the solar panel surface needs to be considered in order to get maximum solar energy. The results of this study can be used by technicians in determining the orientation of solar panel development in an area.

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1. INTRODUCTION

The application of renewable energy has begun to increase along with the high demand for electrification and concerns about climate change. The utilization of renewable energy is also carried out in the Universitas Airlangga. Universitas Airlangga is a study environment located in East Java with a wet tropical climate type with coordinates at latitude 7°16'1"S and longitude 112°47'7"E. In the study environment, a charging station for electric vehicles was built. To fulfill the necessity for electrification of the electric vehicle charging station, this station is equipped with solar panels with a capacity of 5.4 kW. In obtaining peak sun hours (PSH) data, output energy data is taken from Hoymiles microinverter data and is taken every 15 minutes at time intervals of 05:30-18:30.

Solar cells utilize solar energy to be engineered into energy through the photoelectric effect [1], [2]. Materials the amount of energy that can be converted into electrical energy depends on the length of solar irradiation and the size of the power of a solar panel (Watt peak). However, the length of time that the sun shines cannot be said to be effective time. The optimum conversion of solar energy occurs during insolation at the average maximum irradiation time or what is called PSH. PSH is a parameter that states the ratio of the maximum duration of solar radiation in hours per day to the standard intensity of solar radiation which is 1 kW/m^2 [3].

Basically, the solar insolation on the solar panel surface is fluctuating where the intensity increases in the morning and decreases in the afternoon. The effective duration of solar radiation for solar panels affects the high and low PSH. In its application, the photovoltaic semiconductor plate will receive maximum solar irradiation if the direction of the incident photons is perpendicular to the surface of the solar panel [4], [5]. Thus, PSH has a value of 3-7 hours per day depending on the geographical and astronomical location of an area and the slope of the solar panel surface [6]–[10].

The main focus of this research is to analyze the actual value of PSH in Indonesia by using the location of Universitas Airlangga, Surabaya as the analyzing point. Second, with the PSH value determined by analyzing data from the field, it can be used to design a reliable solar photovoltaic power system in Indonesia. Analyzing the PSH value can be used to determine the size and configuration of solar panel array needed for the system. In addition, it can also be used to predict and optimize energy production in solar photovoltaic power systems.

2. METHOD

2.1. Photovoltaic effect

The conversion of solar energy into electrical energy occurs in photovoltaic semiconductor materials through a photoelectric process [11], [12].

$$E_k = W - W_o \tag{1}$$

Where E_k is the kinetic energy needed to move free electron to generate electricity, *W* is the photon energy and W_o is the material threshold energy obtained from:

$$W_o = h\frac{c}{\lambda} \text{ or} \tag{2}$$

$$W_o = h_f \tag{3}$$

where *c* is the Speed of light $(3x\ 10^8\ m/s)$. λ is wave length in meter. *f* is wave frequency (Hz).

2.2. Solar declination

The solar declination reading (δ) is obtained from the coordinates of the globe in terms of the equator coordinates. The value of solar declination is measured by measuring the angle between the equator drawn from the center of the earth to the center of the sun. The process of the earth around the sun on its polar axis can form a slope of 0° - 23,45° [13].

$$\delta = 23{,}45°\sin\left(360°\frac{284+n}{365}\right) \tag{4}$$

Where n is Julian day.

2.3. Latitude and longitude effect

The influence of the intensity of the sun is determined by the location of the area on the earth's surface [14], [15]. The position refers to the astronomical coordinates of latitude and longitude. Figure 1 below explains the solar path of the selected location. The solar path diagram illustrates the comparation of the azimuth to sun height in degrees for an annual cycle. It can be used as a reference for an overview of solar resources within a particular location.

2.4. Tilt

Solar energy can convert maximally into electrical energy if the surface of the solar panel is perpendicular to the direction of the sun's rays (source). The orientation of the construction of solar panels must pay attention to the position of the sun, longitude and latitude [16]–[18]. This is because each region based on geographical and astronomical aspects has a different position.

$$\beta_{max} = \emptyset - \delta \tag{5}$$

Where:
β_{max} : Optimal tilt angle
$\emptyset$: Longitude area
δ : Declination angle

Figure 2 shows the tilt angle of the installed solar cell in Universitas Airlangga. The measurement of the solar panel is conducted by applying magnetic water pass directly into the solar panel. This method can be reassured by using (5).

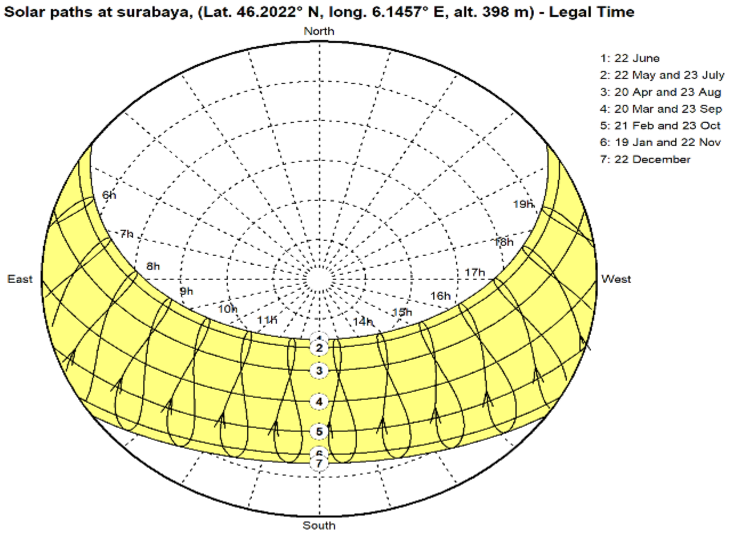

Figure 1. Solar paths based on coordinate of Surabaya, East Java (PVsyst 7.2)

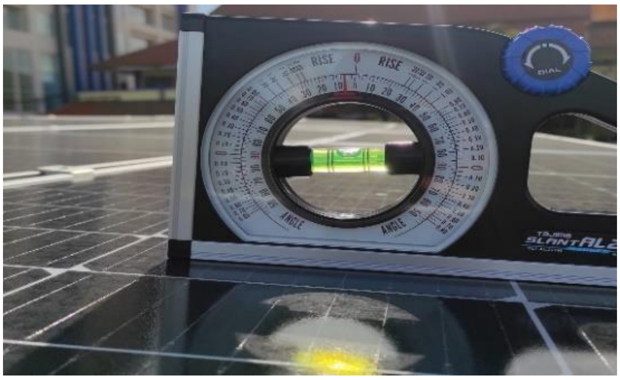

Figure 2. Tilt angle of solar cell in Airlangga University

2.5. Determine peak sun hour

PSH take the solar irradiation interval when energy output increases by 60% until the output decreases by 60% [19], [20]. The process of obtaining Peak Sun Hour (PSH) value can be done by using the equation of nominal peak power or (5). after the maximum output value is obtained, the PSH value can be determined by substituting the peak power value into the equation.

$$P_{pv} = \frac{P_{load}}{PSH \cdot \eta_{system}} \tag{6}$$

Where:

P_{pv} : Nominal peak power (W)
P_{load} : Total energy demand (W)
PSH : Peak Sun Hours (hour)
η_{system} : System efficiency (%)

2.6. Irradiance factor

Solar radiation is the power per unit area received from the sun in the form of electromagnetic radiation measured in the wavelength range of the measuring instrument [21]. Irradiation can be measured in space or at the earth's surface after absorption and scattering of the atmosphere. Irradiation plays a role in predicting the energy productivity of solar power plants. The distribution of irradiation levels across the Java Archipelago is described in Figure 3, with the selected location represented in the figure as the blue mark. The figure explains the irradiation factor within a color range from yellow as lower to orange as the higher value.

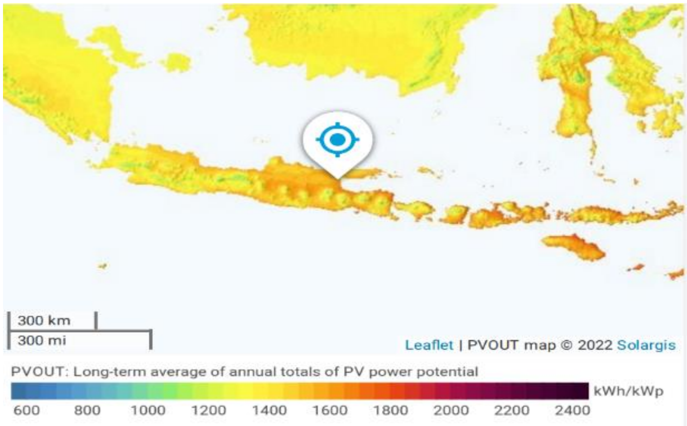

Figure 3. Solar map in Java Archipelago (map solar irradiance on data of year 2021, ENERGYDATA.INFO)

3. RESULTS AND DISCUSSION

In this section will explain the PSH analysis of solar cells found at Universitas Airlangga. In the previous section, the method to get the PSH value was explained and the things that affect the PSH value such as the photovoltaic effect, solar declination, longitude and latitude, tilt surface, and irradiance factor. Through the described method, a graph of the PSH value will be displayed at the observation location. The installed photovoltaic system in the observation location is equipped with a monocrystalline type solar cell which is shown in Figure 4(a), and a panel box with a display to present solar measurement parameters, which are shown in Figure 4(b).

(a) (b)

Figure 4. 5.4 kWp photovoltaic power plant installation in Universitas Airlangga (a) the photovoltaic array, and (b) the control panel

3.1. Peak sun hours analysis

The energy output produced by the solar cell shows a different amount of energy conversion every day. The fluctuating energy output is due to the PSH factor [22]. The PSH value that is less makes the need for solar cells increase. The location of Airlangga University, Surabaya, Indonesia, has an average PSH value of 4.5 hours/day.

Figure 5 shows the data for calculating the PSH solar cell of 5.4 kWh which is calculated manually through real-time solar power station monitoring (S-miles cloud). The value shown by the graph is the PSH value measured at 12 hour intervals. From the graph, it can be seen that the PSH value fluctuates. This fluctuating value is caused by weather factors that can make insolation not optimal and have an impact on low solar irradiation values.

Figure 6 shows the results of the energy output that can be used for electrification of electricity needs. The measurement results are obtained through real time measurements for 3 months. The results obtained, are the results obtained from the average energy output at the PSH interval (4.5 hours) according to the PSH value of the research results. Based on the results shown in Figures 5 and 6, there is a correlation that shows results that are directly proportional to PSH and energy output. From the graph shown, it can be seen that the low PSH in a period will affect the low energy output (and vice versa).

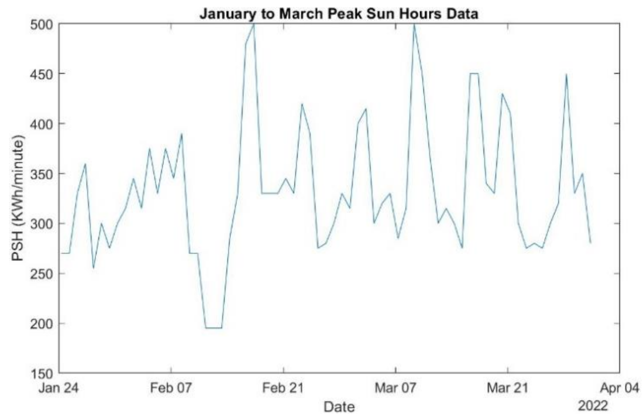

Figure 5. PSH data collection from hoymiles microconverter

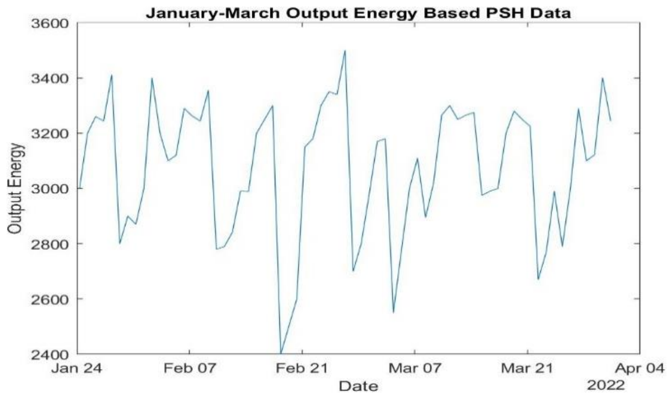

Figure 6. Energy output based on PSH data

Figure 7 shows the results of the power output starting from sunrise to sunset. The power output shown every hour is the result of the average power output for 3 months. The first red line showed in the Figure 7 (the left one) is the time of PSH start point, which more than 60% of the peak power is reached. Besides, the second red line (the right one) is the time when PSH is ended. This means the power decrease into less than 60% of peak power. Based on this average value, the PSH zone can be determined, namely in the graph area bounded by the red line. The PSH solar cells are at intervals from 09:30 to 14:00 (4.5 hours). This PSH value will be used to determine the optimal hour for converting solar energy into electrical energy.

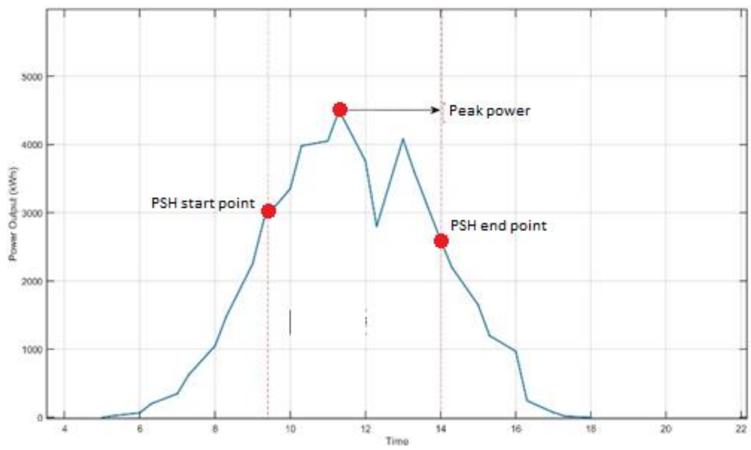

Figure 7. Energy output based on PSH data

3.2. Energy output from solar cell

The on grid solar cell photovoltaic installed in the Airlangga University study area has a capacity of 5.4 kWh a 24 Volt system. The normalized energy, performance ratio, global incident in coll, and power injected into grid values are values analyzed using PVsyst software. The orientation of the PVsyst has been adjusted including geographical and astronomical coordinates, the slope of the solar cell surface, and solar irradiation data for the area (Airlangga University, East Java) for one year. Thus, the PSH value and energy output from solar panels can be analyzed regarding the relationship between analyzed from the software.

Figure 8 explains the system's capability in producing power month-by-month in a year. The figure shows the system's daily useful energy referred to the nominal power and the losses that occurred. Those losses include the collection losses that happened because of thermal, wiring, shading, or other inefficiencies [23], [24]. Also, the system loss which in the case of the proposed method happened because of inverter inefficiencies [25]–[27]. While Figure 9 shows the system's effectiveness in producing energy if the system continuously working.

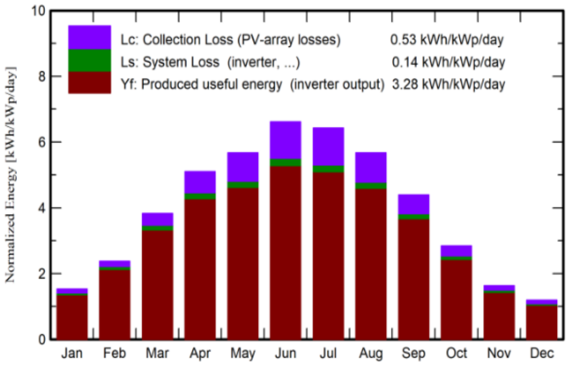

Figure 8. Energy productivity every month

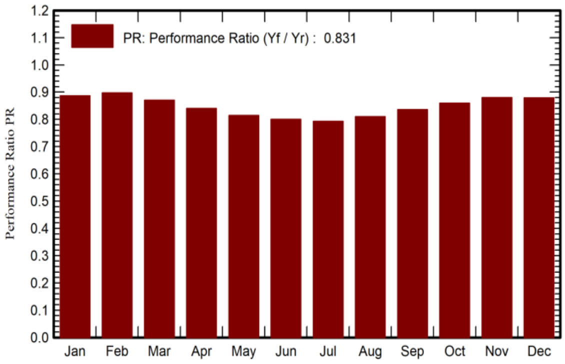

Figure 9. Monthly performance ratio

Figure 10 shows a graph that represents the photovoltaic daily production. The graph shows a correlation between daily irradiation and system daily productivity. While Figure 11 shows the accumulations of all energies registered by the system during the simulation period, with the instantaneous output power injected into the grid [28]–[30].

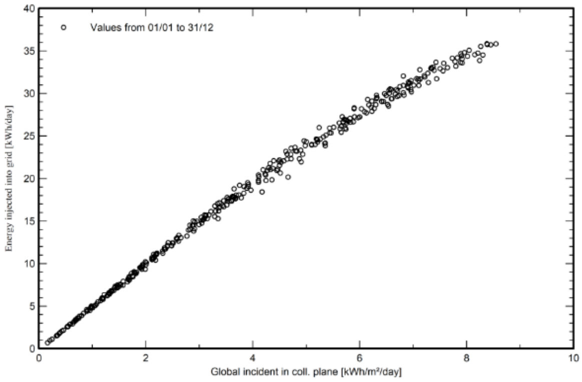

Figure 10. Daily energy supply to daily irradiation

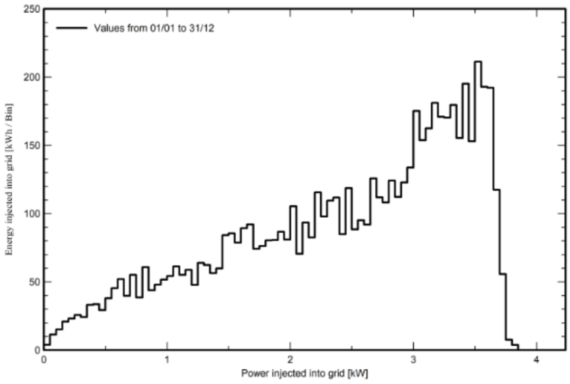

Figure 11. Power and energy supply

4. CONCLUSION

PSH is an indicator that determines the amount of energy output required in the installation of solar panels, especially on 5.4 kWh solar panels in the Airlangga University area, Surabaya, East Java. Based on PSH data collection using the observation method, the average PSH in the observation area was 4.5 hours. The PSH value can produce an average energy of 3.28 kWh/day and a performance ratio value of 0.831. Thus, the analysis of the PSH value can be a reference for technicians and renewable energy consumers in solar panel installations.

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