The Feasibility of Agrivoltaic Setting in Palembang; Toward the Implementation of Solar Powered Automatic Agriculture in Indonesia

Tresna Dewi[1](✉), Yurni Oktarina[1], Sipronі Sipronі[2], and Sri Rezki Artini[3]

[1] Electrical Engineering Department, Politeknik Negeri Sriwijaya, Srijaya Negara, Palembang, Indonesia
tresna_dewi@polsri.ac.id

[2] Mechanical Engineering Department, Politeknik Negeri Sriwijaya, Srijaya Negara, Palembang, Indonesia

[3] Civil Engineering Department, Politeknik Negeri Sriwijaya, Srijaya Negara, Palembang, Indonesia

Abstract. Implementing energy from the sun to power a digital farming concept in Palembang can significantly benefit agriculture. This study's objective of digital farming is to develop solar-powered automatic agriculture. Agrivoltaic refers to the combination of agriculture and solar energy generation. This research looks into the viability of agrivoltaic installations in Palembang, Indonesia. The proposed agrivoltaic design sizing is carried out using SAM simulation and validated with experimental results over three days. The average irradiance data from the simulation indicates that the highest irradiance in Palembang is 900 W/m^2, while experimental results indicate that the highest irradiance in Palembang is 1300 W/m^2. The PV system sizing demonstrates that the designed agrivoltaic requires four PV panels, each with a capacity of 180 Wp, and the irradiance data demonstrates that the solar energy potential in Palembang is more than sufficient to power the proposed agrivoltaic system method.

Keywords: Agrivoltaic · Digital Farming · PV System · Solar Energy

1 Introduction

Agriculture is an important industry that helps the community survive, and Agriculture that is advanced and superior ensures food security and community welfare. This fact forces the government and society to continue looking for the best way to increase agricultural production in the face of increasingly complicated agricultural problems, such as reducing agricultural land due to changes in land function into housing or shops [1]. Agriculture is also losing traction, with the younger generation preferring to work in an office rather than agricultural work, which is considered less cool.

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Given the problems mentioned above, it is critical to improve agriculture in terms of quality and quantity. This agricultural improvement can be accomplished by automating the farm, simplifying farmers' work, and increasing agricultural production [2–6]. Because not all farms have a stable power source or even electricity, agricultural digitization must be accompanied by a continuous electricity supply.

The limited or unstable electricity supply in Palembang, a city in the tropical country of Indonesia, can be overcome by utilizing unlimited solar energy. Agrivoltaic, or agriculture and photovoltaic, refers to the combination of implantation technology for generating electricity using solar power and agriculture that benefits from it [7–10]. Agrivoltaic makes a trade-off between using fertile land for PV panel installation and land for cultivation. Agrivoltaic is the ideal solution to the problem of insufficient electricity and ensuring that agriculture can continue even if the land must be divided for installing PV panels. Jing et al. in 2022 present the high potential application of agrivoltaic in the city area, especially on rooftops [9], Malu et al. in 2017 investigate the agrivoltaic implementation for grape farming in India [10], and Amaducci et al. in 2021 present agrivoltaic system to ensure the balance benefit and use of land for farming and electricity production [11].

This paper presents the feasibility of agrivoltaic setting in Palembang toward implementing solar-powered automatic agriculture in Indonesia [12–14]. The novelty of this research is that it comes with the idea of implementing agrivoltaic in tropical islands by giving the alternative of its implementation without comprising the arid land. The contribution of this research is that this paper can be a reference for those researching the possibility of applying agrivoltaic in similar weather settings.

2 Proposed Method

Agrivoltaics' technical feasibility should consider the potential in an urban context, particularly in cities, dry areas, open-air farming, and greenhouses. This analysis may partly consider the interconnections of energy to power the city area and increase the possibility of providing food for city areas, which requires expertise from different sciences. Hence, currently, the implementations of agrivoltaic are limited to developed countries, while countries in the third world require them the most.

This paper proposes the integrated design of agrivoltaic systems to maximize the potential of agrivoltaics in cities or remote areas. The power output of the designed PV system is estimated by measuring available irradiance using a power meter. The design system is linked to a simulation demonstrating the required power for the agrivoltaic system proposed in this study.

2.1 Agrivoltaic System Design

Agrivoltaic system benefits from solar energy to create an automatic agriculture system. This type of cultivation promises easier and cheaper in the long run. The agrivoltaic system proposed in this paper is illustrated in Fig. 1. The PV panels are installed nearby the plants, and only some parts of the plants are affected by shadowing.

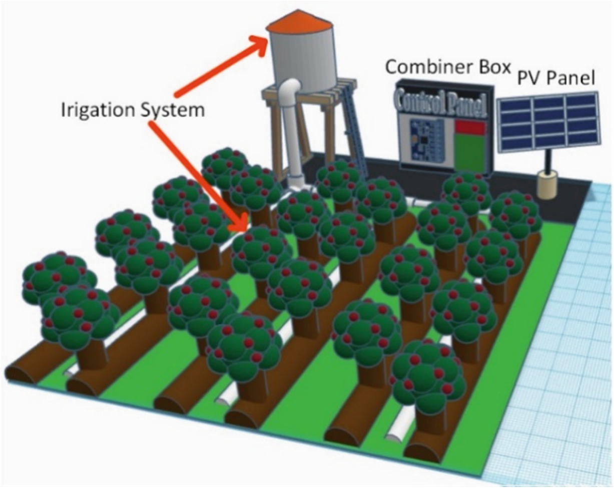

Fig. 1. The agrivoltaic design considered in this study.

Figure 1 depicts the irrigation system and fertilizer sprayer (not shown), combiner box for the PV system, and plant positions that share sun radiation between crop's photosynthesis and electricity generation by solar panels. As a result, this agricultural type can self-sustain.

2.2 PV System Design

Figure 2 depicts this research's PV system design, including PV panels, a battery charger controller, a battery, an inverter, and electrical loads. The solar panels installed here are polycrystalline. The polycrystalline PV panel has the same efficiency as monocrystalline and is easier to manufacture. A charge controller is required to ensure no undercharge or overcharge. Batteries are required to save solar energy, and they can power electrical devices at night. PV panels produce DC electricity, but most electrical loads require AC. As a result, an inverter is installed to facilitate this condition. The electrical loads considered in this study are sensors and pumps.

The PV panels consist of solar cells that are considered ideal diodes. The circuit for an ideal diode is Fig. 3. The modeling is completed with shunt losses (R_{sh}) in Ω, and series resistor (R_s).

The current generated by solar cell based on Fig. 3 is given by:

$$I = I_{ph} - I_0\left(e^{q\frac{V+IR_s}{nkT}} - 1\right) - \frac{V + IR_s}{R_p}, \tag{1}$$

and

$$I = I_0\left(e^{\frac{qV}{nKT}} - 1\right) - I_{ph}, \tag{2}$$

where I is the current produced by a solar cell (A), I_{ph} is light-generated current, V is the voltage (V), $e^{\frac{qV}{nKT}}$ is the Boltzmann factor, Boltzmann constant is depicted as k, where

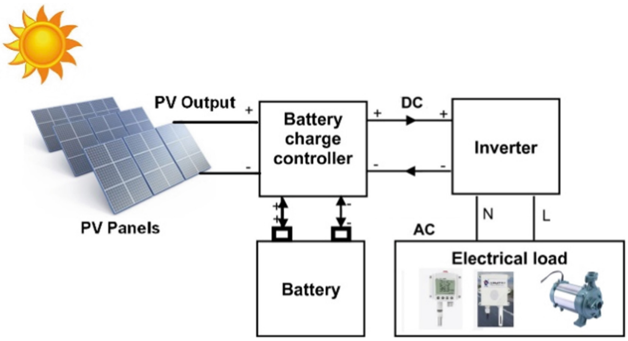

Fig. 2. The schematic of the PV system design for agrivoltaic

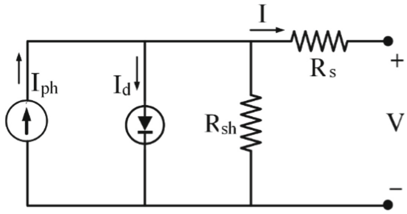

Fig. 3. Solar cell as an ideal diode

1 $k = 1.380649 \times 10^{-23}$ m^2 kg s^{-1} K^{-1}, R_{sh} is shunt losses (Ω), and R_p is power losses (Ω). The open-circuit voltage is given by

$$V_{oc} = \frac{nkT}{q} \ln\left(\frac{I_{out}}{I_o} + 1\right). \tag{3}$$

Solar panel efficiency (η) is defined as the comparison between the power input (P_{in}) dan the generated power output (P_{out}) and is given below:

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% = \frac{I_{mp} \cdot V_{mp}}{P_{in}} \times 100\%,$$

$$\eta = \frac{I_{sc} V_{oc} FF}{P_{in}} \times 100\%, \tag{4}$$

where I_{mp} is the maximum current, V_{mp} is the maximum voltage, and fill factor (FF) is the maximum power generated by the panel, as shown in Fig. 4.

2.3 Sizing System Design

The sizing of the PV system shown in Fig. 3 starts by calculating the total energy demand of the system or electrical load installed in agrivoltaic system in Fig. 1 [15]. The total Energy (E_r) required is

$$E_r = \frac{E_{daily}}{\eta_{overall}}, \tag{5}$$

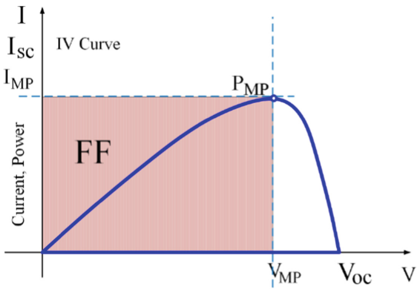

Fig. 4. The maximum power generated by a PV panel

where E_{daily} is the daily average energy demand and $\eta_{overall}$ is the efficiency of the overall load installed.

The maximum power (P_p) of the system is calculated as

$$P_p = \frac{E_r}{T_{min}}, \tag{6}$$

where T_{min} is the minimum sunshine in a day (hours/day).

The total current (I_{DC}) needed is given by:

$$I_{DC} = \frac{P_p}{V_{DC}}, \tag{7}$$

where V_{DC} is the total voltage.

PV panels should be connected in parallel and in series. The number of panels that are connected in parallel (N_P) is calculated as

$$N_P = \frac{I_{DC}}{I_r}, \tag{8}$$

where I_r is PV panel's rated current.

The series PV panels (N_s) is

$$N_s = \frac{V_{DC}}{V_r}, \tag{9}$$

where V_r is the PV panel's rated voltage, and the total number of PV panels (N_T) installed are

$$N_T = N_s \times N_p. \tag{10}$$

Battery sizing is started by calculating the amount of energy storage by multiplying the autonomy days and power demand. The result of this calculation is E_{rough}, and the Energy safe for the system (E_{safe}) is given by

$$E_{safe} = \frac{E_{rough}}{M_{DOD}}, \tag{11}$$

where M_{DOD} is the maximum depth of discharge of the batteries. The capacity of the battery needed is

$$C = \frac{E_{safe}}{V_b}, \tag{12}$$

and V_b is the battery-rated voltage. Hence the number of batteries ($N_{battries}$) needed is

$$N_{battries} = \frac{C}{C_b}, \tag{13}$$

where C_b is capacity of one of the battery.

The number of the battery connected in series and parallel is given by

$$N_s = \frac{V_{DC}}{V_b}, \tag{14}$$

and

$$N_P = \frac{N_{battries}}{N_s}. \tag{15}$$

The charge controller required in a PV system is defined by finding the safe factor (F_{safe}) by

$$I = N_{SC} \times N_s \times F_{safe}, \tag{16}$$

and the number of controllers ($N_{controller}$) is calculated by

$$N_{controller} = \frac{N}{Amp_{each\ controller}}. \tag{17}$$

3 Result and Discussion

This study looks into finding an agrivoltaic system's design and examines the feasibility of agrivoltaic application in Palembang. This design system presents the alternative for automatic agriculture as one effort to overcome the agriculture problems and support government policy in increasing solar energy implementation in Indonesia.

3.1 Agrivoltaic System Sizing

Agrivoltaic system benefits from solar energy to create an automatic agriculture system. This type of cultivation promises easier and cheaper in the long run. The agrivoltaic system considered in this study is shown in Fig. 1. The PV panels are installed nearby the plants, and only some parts of the plants are affected by shadowing.

Table 1 shows the electrical loads considered in this study, including sensors and pumps that need to run at a specific time, such as the sensor needing to sense the plantation environment for 24 h and the pump for irrigation needing to run only for 4 h.

Table 1. The total energy demand of electrical loads installed in this study.

No	Components	Qty	P (W)	Op. Hour	Wh AC
1	Pump for Irrigation	1	38	4	152
2	Pump for Sprayer	1	60	2	120
3	Pump for Nutrition	1	38	2	76
4	Board Controller Arduino	1	9	2	18
5	Ambient Temperature and Humidity Sensor	2	5	24	240
6	Soil Humidity Sensor	6	5	24	720
7	CO2 Sensor	1	5	24	120
8	Soil pH Sensor	6	5	24	720
9	Voltage and Current Sensor	2	5	24	240
10	Irradiance meter	1			0
Total Power (W)			170		
Total Energy Load (TE)					2,406
20% TE					481
TE + 20%					2,887

The steps of realizing the PV system to power the agrivoltaic system are

1. Sizing PV Panels
   The total energy of electrical loads given in Table 1 gives

$$E_r = \frac{TE + 20\%}{\eta_{panel}} = \frac{2887}{0.8},$$

$$E_r = 3609 \text{ Wh}, \tag{18}$$

   where TE + 20% is given in Table 1, and η_{panel} is the PV panel coefficient. Hence, the number of PV panels required for the designed agrivoltaic system is

$$N_p = \frac{E_r}{\text{Irradiance} \times 180},$$

$$N_p = \frac{3609}{4.67 \times 180} = 4.29 \text{ Panel}, \tag{19}$$

   Equation 19 shows that the PV panel required for the designed agrivoltaic system is 5 panels of 180 Wp, rounding from 4.29 PV panels.

2. Sizing Battery
   The number of batteries ($N_{batteries}$) needed to save electricity produced by the PV panels in Eq. 19 during the day are:

$$N_{battries} = \frac{(TE + 20\%) \times T_{min}}{V_B \times C_p \times M_{DOD}},$$

$$N_{\text{battries}} = \frac{2887 \times 4}{12 \times 200 \times 0.8},$$

$$N_{\text{battries}} = 6 \text{ batteries.} \tag{20}$$

where No sun days is the assumption of the number of cloudy days in a week, the battery capacity choice in this study is 200 mAh, and M_{DOD} is 80%.

3. Sizing Charge Controller
The charge controller that will be implemented in this study has the specification of DC12V/24V/36V/48V 60A; hence:

$$I_{\text{Avg SSC}} = I_{SC} \times N_P \times F_{\text{safe}}$$

$$I_{\text{Avg SSC}} = 12.28 \times 4 \times 1.25 = 66 \text{ A} \tag{21}$$

where I_{SC} panel adalah 12.28 A; hence, the number of charge controller required is sehingga jumlah charge controller ($N_{\text{controller}}$) yang diperlukan adalah

$$N_{\text{controller}} = \frac{66}{60} = 1. \tag{22}$$

4. Sizing Inverter
Only one inverter is used in this study because it can accommodate the total power of all the electrical loads (170 W); thus, the inverter installed has a capacity of 200 W because it is available on the market.

3.2 Agrivoltaic System Feasibility

The Feasibility of Agrivoltaic Setting in Palembang is investigated by simulating the design system in SAM to show the irradiance and other environmental and weather aspect to define the possibility of self-sustained automatic agriculture. The simulation result of irradiance, wind, humidity, and ambient temperature are shown in Figs. 5 and 6.

A constant irradiance value over a year ensures a steady energy supply to turn on and run an automated agrivoltaic system. Because of the high humidity in Palembang, farmers choose plants suitable for hot and humid weather, such as chili, which has a high selling value. Wind speed indicates the speed of cloud movement and can reduce PV panel surface temperature.

The simulation data is validated with irradiance taken in 3 days, where during the day, the high irradiance is recorded as shown in Fig. 7. The average irradiance data from the simulation shows that the highest irradiance in Palembang is 900 W/m^2; however, experimental results show that the highest irradiance in Palembang is 1300 W/m^2.

The energy yield resulting from the high potential of energy photons brought by the irradiance is enough to show that agrivoltaic is an excellent option for agriculture and renewable energy applications in Indonesia. This new technology can shift the paradigm of fossil fuel implementation to green energy. Hence, the implementation of solar-powered automatic agriculture is feasible.

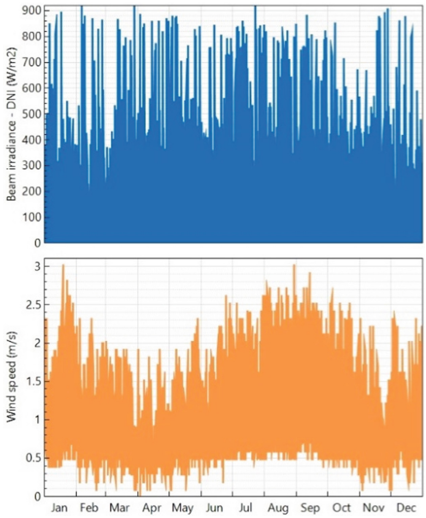

Fig. 5. Irradiance and wind speed in Palembang for a year.

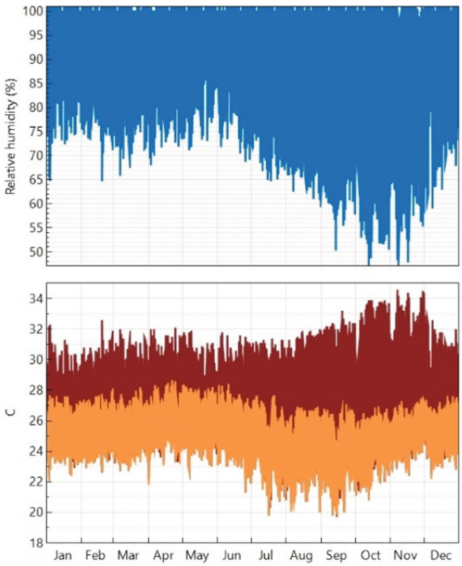

Fig. 6. Relative humidity and temperature in Palembang for a year.

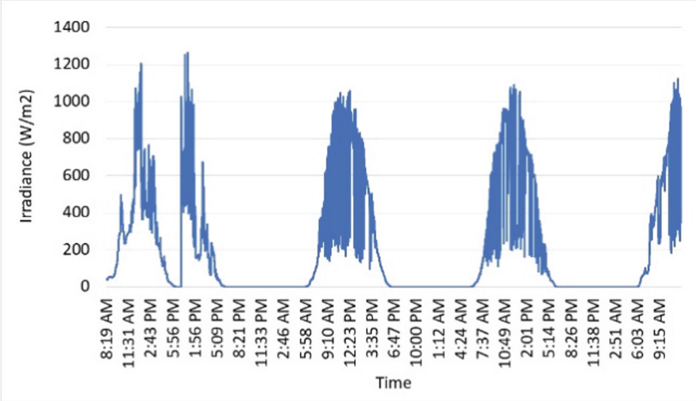

Fig. 7. Irradiance for 3 days in Palembang

4 Conclusion

This paper examines the viability of installing agrivoltaic systems in Palembang to implement solar-powered automatic agriculture in Indonesia. The energy demand required to realize the agrivoltaic setting in Palembang is used to calculate the agrivoltaic design system. The PV system sizing shows that the designed agrivoltaic requires four PV panels, each with a capacity of 180 Wp, and the irradiance data shows that the solar energy potential in Palembang is more than enough to power the proposed agrivoltaic system method.

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