Design and Test of Agri-Voltaic System

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Abstract: Agri-voltaic system is the combination between solar photovoltaic power generation and plant cultivation. A 480 Wp ground-mounted solar panel system was designed and constructed. After that, a plant plot sizing 1 x 7 m under this solar panel was design as well as 175 vegetations of bok choy were then grown. The potential of agri-voltaic system consisting of efficiency of solar power generation, the bok choy yield and the land equivalent ratio of system were monitored and evaluated. The system could generate power at around 1.05 kW/day (31.00 kW/month). In addition, 8.00 kg/plot of bok choy yield was obtained. The total value of both systems could make up to $6.34 a month ($3.73 and $2.61 from solar power generation and plant production, respectively). The land equivalent ratio (LER) of system was 1.80 which was indicated that the agri-voltaic system could increase the land value up to 80%.

Keywords: Solar power generation efficiency, Agri-voltaic system and Solar cell.

1. Introduction

Currently, Thailand has photovoltaic (PV) power generation capacity of 2,819 MW. There are covered an area of 9,020 hectare (Chimres, & Wongwises, 2016) but the area under the solar panel has not been utilized. In 2015, the government of Thailand has a policy to generate 6,000 of photovoltaic (PV) power generation. (Achawangkul, & Blueprint, 2015) which needed more area for install solar panels to generate electricity. The photovoltaic (PV) power generation capacity of 1 MW covered an area of 3.2 hectare (Ong, Campbell, Denholm, Margolis, & Heath, 2013). Increasing of solar power generation will inevitably require more land area for installation which may affect not only the land use competition, but also food security in the future.

Asian Development College for Community Economy and Technology (adiCET), Chiang Mai Rajabhat University is concerned about energy conservation, higher efficiencies, and use of renewable energies in the integration to the local community. adiCET aims to be the learning center for green technologies to showcase real applications for sustainable living. adiCET is education institution that offers graduate education. Community Energy and Environment Program. adiCET has energy and environment experts and ready in terms of personnel, tools and place for conducting solar research projects. The researcher of adiCET was to investigate a suitable configuration for space utilization under the PV panels for 3 configurations: a water pond, a chili cultivation and a grass plantation and the PV reference cell, temperature sensor and DC meter was installed. The Results indicated that water pond and a chili cultivation were suitable configuration for promoting the power production (Kumpanalaisatit, Jankasorn, Setthapun, Sintuya, and Jansri, 2019). Therefore, in order to solve the problem of the aforementioned areas, the concept of solar power generation is combined with agriculture known as Agri-voltaic systems which is the most useful of the land to generate electricity from solar energy in the same land at the same time. However, the combination of solar power generation and agriculture requires to experiments in order to obtain a prototype that is suitable for each area. Therefore, this research focuses on design and construct the ground-mounted solar panel system, evaluate the efficiency of solar power generation and analyze growth and yield of Bok choy under solar panels.

2. Research Objectives

The objectives of this research article were 1) to design the Agri-Voltaic System, and 2) to evaluate the efficiency of photovoltaic (PV) power generation and the growth and yield of bok choy was analyzed.

3. Research Methods

3.1 Design of Agri-Voltaic System

The design of Agri-Voltaic System is planning to installation of the ground-mounted photovoltaic (PV) power generation and setting the plant cultivation system for Co-production following steps:

1. Design and installation of the ground-mounted photovoltaic (PV) power generation

The ground-mounted photovoltaic (PV) power generation capacity of 480 Wp was designed and installed in the purpose of generating electricity. There are 4 polycrystalline PV modules installed with a solar charge controller, 1 battery and an inverter in order to distribute the power to the load (45 W electric fan). The structure is tilted at an angle of 18 degrees to the earth.

2. Setting the plant plot for crop cultivation

The soil under PV panels was prepared and ploughed with raised beds of 7 cm^2 (7 x 1 m), as seen in Fig. 1.

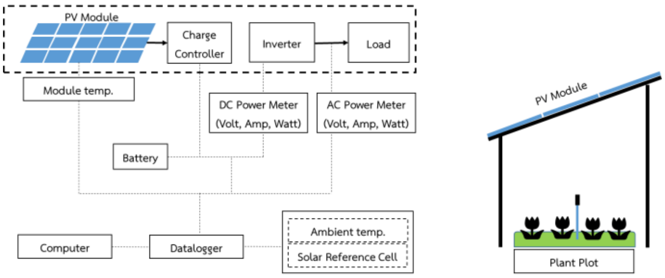

Fig.1 Design of Agri-Voltaic System

3.2 Evaluate the evaluate the efficiency of photovoltaic (PV) power generation

The Method for evaluate the performance of solar power generation systems reference to standard International Electrotechnical Commission: IEC 61724, which contains important parameters for evaluating the performance of photovoltaic power generation systems (Pirawut Chinnaworanganyang et al, 2015) as equation 1 - 4.

$$Y_a = \frac{E_{pv(DC)}}{P_{o(installed)}} \quad (1)$$

$$Y_f = \frac{E_{pv(AC)}}{P_{o(installed)}} \quad (2)$$

$$Y_r = \frac{H_i}{G_{STC}} \quad (3)$$

$$PR = \frac{Y_f}{Y_r} \times 100 \quad (4)$$

When

1) Ya is array Yield (kWh/kWp)
2) Yf is final Yield (kWh/kWp)
3) Yr is reference Yield (kWh/kWp)
4) PR is Performance Ratio (%)
5) $E_{pv(DC)}$ daily energy contributed to the load by PV plant (kWh)
6) $E_{grid(AC)}$ daily energy consumed by the load (kWh)
7) Po (installed) is capacity (kWp)
8) H_i is solar radiation (kWh/m^2)
9) G_{STC} is solar radiation standard test condition: STC (1 kW/m^2)

3.3 Evaluate the evaluate the growth and yield of bokchoy

1. The height of plants, the number of leaves, the size of leaves and the weight of plants were measured 35 plant per plot. All of the parameter were recorded every 7 days, starting from the 7th day after transplanting to the harvest date.

2. At 35 days after transplanting, thirty-five plants per plot were harvested, weighed, and recorded.

4. Installation of PV system

4.1 Installation of ground-mounted solar power generation

4.1.1 Structure

The size of structure ground-mounted solar power generation is 5,000 × 4,000 mm. The pole is galvanized steel box, size 101.6 x 50.8 mm. There are 4 poles, the spacing between the poles is 3,000 x 2,500 mm. The steel for fixing the solar panels is galvanized steel box, size 2,000 x 2,000 mm, 4,000 mm, 8 steel as seen in Fig. 2.

Fig.2 INSTALLATION OF PV SYSTEM STRUCTURE

4.1.2 Installation of solar panels and smart boards

Solar panel installation of solar power system by installing solar panels, 120 watts 18.7 volts, 6.42 amperes, 4 panels each to be connected in parallel to the power of 480 watts. Installation characteristics will be installed in the middle of the structure. The smart board was installing in other area of structure as seen in Fig. 3.

Fig.3 Installation of PV panel and smart board

4.1.3 Installation of the control box

The connecting of PV power generation is using an MC4 connector and a 2.5 mm2 PV1-F solar cable is connected from the solar panel to the electric control box. Which the electric control box of the solar power system consists of Charge controller and inverter as seen in Fig. 4.

Fig.4 Installation of the control box and cable connection

4.1.4 Installation of battery

The battery installation is connect from the charge controller, to the battery, and connected to the inverter to convert the direct current into AC electricity as seen in Fig.5.

Fig.5 Installation of the battery

4.1.5 Installation of PV reference cell

The PV reference cell was installed for measure solar radiation as seen in Fig.6. There are record the data by data recorder as seen in Fig.7.

Fig.6 Installation of PV reference cell

Fig.7 Collection data from PV reference cell

4.1.6 Installation of power meter

Power meter was installed for measure electricity production of the solar power system that is produced in conjunction with agriculture. To compare the efficiency of electricity as seen in Fig.8.

Fig.8 Installation of the meter

5. Setting up of the plant plot

5.1 Plant plot preparation for yield evaluation of plants grown under solar panels.

a plant plot sizing 1 x 7 m under this solar panel was design as well as 175 vegetations of bok choy were then grown as seen in Fig.9.

Fig.8 Setting up of the plant plot

5.2 Installation of a water system

Installing a water system by using a 6-inch PCV water pipe, then installed a water filter system. Then installed a PE pipe for drip system as seen in Fig.9.

Fig.9 Installation of irrigation system

6. Results

6.1 Solar power generation

Solar power generation data collection includes information Current (amperes) and voltage obtained from solar panels (volts). The data was evaluating the power produced from the system. In addition, it also collects the factors that affect solar power generation by collecting solar radiation intensity and solar panel temperature data. As the following details:

6.2. solar radiation

The collecting solar radiation data was conducted during plant growing under solar panels from October 21 - November 13, 2021, a total of 24 days. It was found that on November 10, 2021 the mean solar radiation was the highest of 546 watts per square meter. On October 30, 2021, the mean solar radiation was the lowest at 118 watts per square meter. And an average of 24 days of solar radiation is 385 watts per square meter as seen in Fig.10. From Figure 11, it can be seen that the mean of solar radiation for this period varies with weather conditions. That is to explan, the data collection period is the end of the rainy season, so there will be some days of rain and the solar radiation values of each day are different. The daily average of the solar radiation intensity showed that the solar radiation was high during 11.00 - 15.00 hrs. Between 500 - 790 watts per square meter. This shows that this is the period when the solar power system can generate the highest amount of electricity.

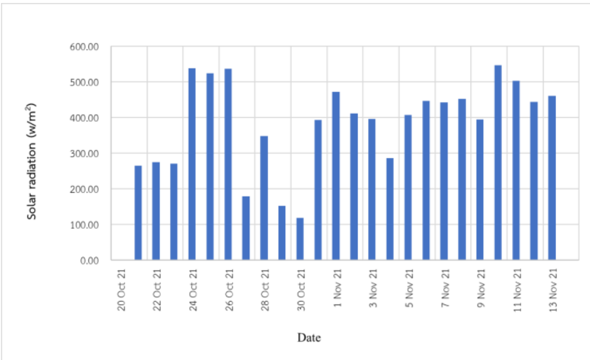

Fig.10 Average solar radiation from October 21 - November 13, 2021

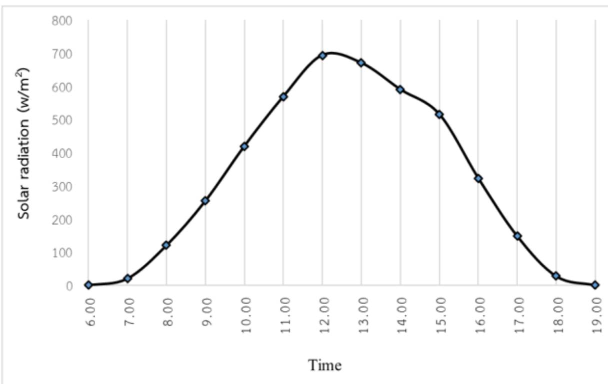

Fig.11 Average solar radiation from perday October 21 - November 13, 2021

6.3 Solar panel temperature

The collecting data of solar panel temperature and ambient temperature during the time of from October 21 - November 13, 2021, a total of 24 days. It was found that the solar panel temperature and the ambient temperature were related, that is, when the air temperature rises, the solar panel temperature increases. The maximum temperature of solar panels and ambient temperatures were 46.19 and 30.00 degrees Celsius, respectively, the lowest temperatures were 24.78 and 24.00 degrees Celsius, and the 24-day mean temperatures were 38.33 and 27.21, respectively. The data shows that the average temperature is relatively consistent. The temperature of the solar panel varies with the solar radiation intensity. Therefore, the temperature of the solar panels on rainy or less sunny days is a little higher than the air temperature as seen in Fig.9.

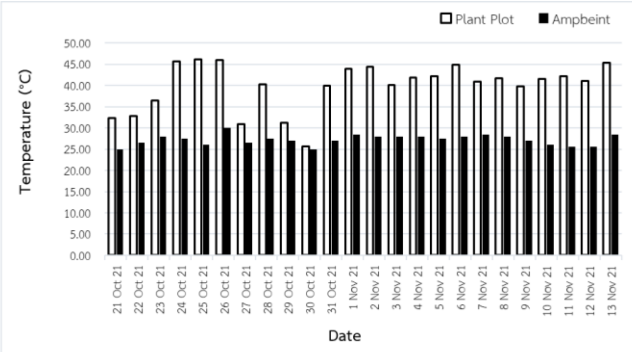

Fig.12 Temperature

6.4 Solar power generation

The collecting data of Current (amperes) and voltage from solar panels (volts) to calculate the power generated by the system during October 21 - November 13, 2021, a total of 24 days. It was found that the Agrivoltaic system, size 480 Wp, can produce a total of 25,000 watts or 25 units of electricity, an average of 1,052 watts per day which November 10, 2021 it can generate electricity as high as 1,839 watts, and October 21, 2021 it can produce as low as 356 watts. The average solar power was found that the solar power system produced in Agrivoltaic system can produce high electricity at 12.00 hours.

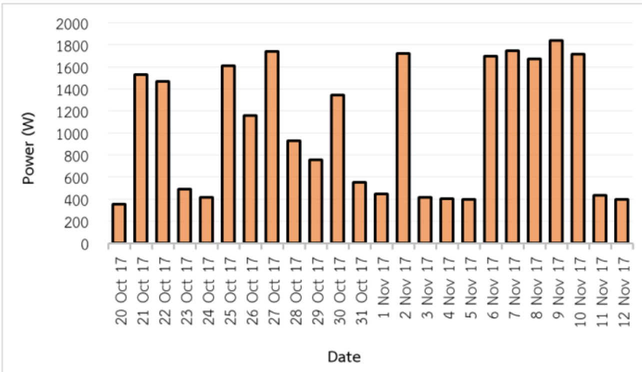

Fig.13 Solar power generation

6.5 Growth and yield of plant

The height of vegetables grown under solar panels in the 5th week was 3.6 centimeters higher than that of normal light conditions. The graph shows that the height of the vegetables grown under solar panels tends to increase steadily due to insufficient light intensity factor as seen Fig. 14.

Number of leaves: 8 leaves of vegetables that were planted under the solar panel at the 5th week. as seen Fig. 15.

It was concluded that growing plants under solar panels had no effect on leaf growth.

The width and leaf length of the plants were found that the width and leaf length of the vegetables grown under the solar panel were 4.53 cm and 11.12 cm respectively.

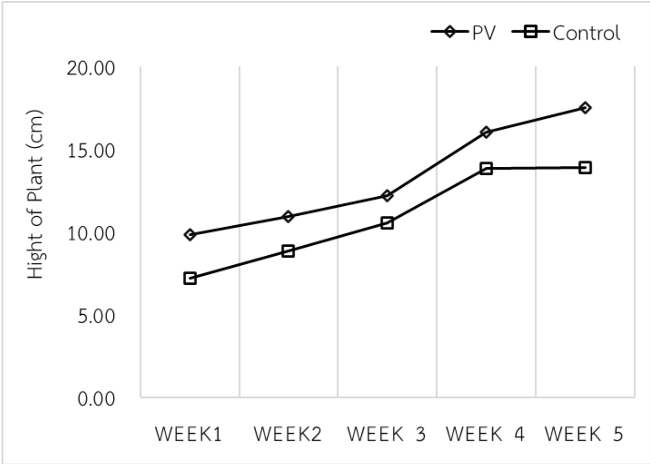

Fig.14 Hight of plant

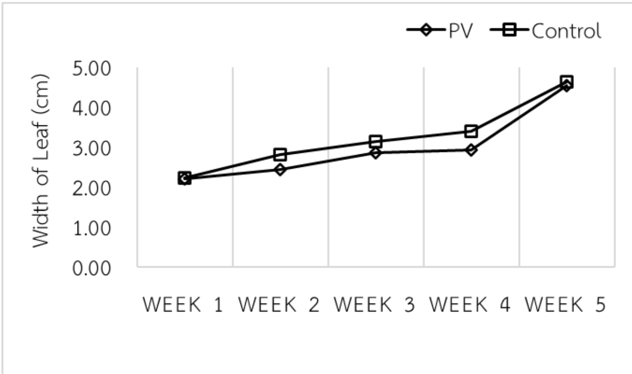

Fig.16 Width of Leaf

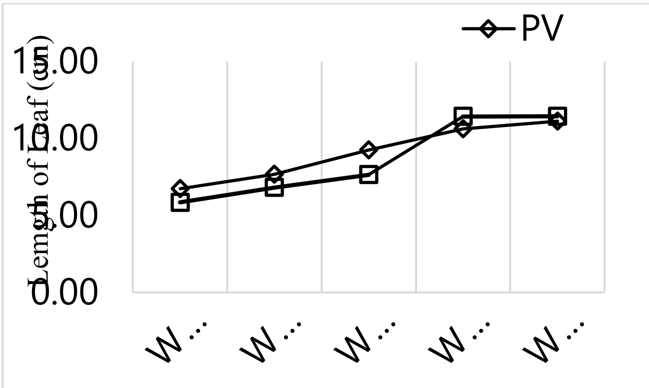

Fig.17 Length of Leaf

The data collection of plant weights and root weights of bok choy that grown under solar panels was found that growing under solar panels had an average of 48.61 grams per plant. The total yield was 1.8 kg.

Table 1 Fresh weight and total yield of bok choy that cultivation under the PV panel

Plant	Fresh Weight (gram/plat)							total (g)	yield (kg)
	1	2	3	4	5	6	7		
Shoot	6.7	18.4	8.1	5.9	2.7	3.1	3.7	48.6	8.5
Root	0.8	1.4	2.0	0.4	0.30	0.6	1.7	7.3	

7. Discussions

The ground-mounted Solar power generation that combine with agriculture could generate electricity similar to or more than a solar power system that is not co-produced with agriculture because such a power system is designed for the purpose of generating electricity. The crop cultivation under the photovoltaic panels may result in lower panel temperatures. The voltage increases and there are results in more electricity, Rajvikram and Leoponraj (2018) confirmed that the efficiency of solar panels can increase to 14% when the solar panel's temperature drops around 5 ° C. Peng, Herfatmanesh, & Liu (2017) also concluded that the thermal cooling technique of solar panels can increase solar panel efficiency. This is consistent with the results of Anucha Dee Phang and Promchaisuphan (2018) said that Solar panels installed as a solar tracking system in combination with a water-cooling system produced approximately 16.9 W more than fixed and non-cooled solar panels, or approximately 28.36 percent. The potential yield of boy choy that grown under solar power generation system is 20 percent less than the general cultivation. However, the considering of land equivalent ratio was showed that the agrivoltaic system could added value of the land (LER = 1.8) Which increase added value of the land by 80 percentage. The results of this land use efficiency assessment are consistent with the Valle et al., 2017 and Dupraz et al., 2011. They are assess of land use efficiency and found that the values of LER is 1.67 and 1.73, respectively, which show that the cost-effectiveness and feasibility of installing a solar power system with agriculture.

8. Recommendations

8.1. Recommendations for Practices

This research is test of agrivoltaic system by evaluate photovoltaic output and yield of crop that grown under the PV panel which there are without Control for comparison. Therefore, the researcher recommends that the testing of agrivoltaic system should be conducted with control for comparison the result.

9. Conclusion

The 480 Wp ground-mounted solar power generation system could generate power at around 1.05 kW/day (31.00 kW/month). In addition, 8.00 kg/plot of bok choy yield was obtained. The total value of both systems could make up to $6.34 a month ($3.73 and $2.61 from solar power generation and plant production, respectively). The land equivalent ratio (LER) of system was 1.80 which was indicated that the agri-voltaic system could increase the land value up to 80%.

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