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Smart Solar Powered Hydroponic Close-Loop Low-Land Condition (*Smart-HCO₂*)

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Abstract

The hydroponic system is one of the modern agricultural techniques that is popular due to its easy control, space efficiency, and water-saving benefits. However, manually administering fertilizer in large quantities can be burdensome for farmers. To address this, the project introduces an automated hydroponic system with a sensor-based fertilizer concentration detection mechanism connected to a nutrient reservoir. Water continuously flows to the plant roots throughout the day. The entire system operates on solar energy, utilizing a solar panel 405W with 12V 200Ah lead-acid battery and a 1200W inverter with MPPT. Testing was conducted with cherry tomatoes, bell peppers, and Japanese cucumbers from August 2023 until June 2024. The plants were adjusting the fertilizer concentration to 700ppm in the first two weeks and increased it to 1200ppm in 3rd and 4th weeks, the plants began flowering early—within 30 days of being transferred to the hydroponic system. This approach not only saves electricity but also optimizes fertilizer usage and reduces plant maintenance time. In conclusion, this project contributes to sustainable agriculture by harnessing green energy technology while minimizing fertilizer and water consumption and reducing environmental pollution.

1. Introduction

Solar energy is one of the most well-known energy and the technologies regarding solar energy is growing rapidly. The reasons behind the rapid growth of solar energy technologies were because of the coverage of sunlight that containing the energy is throughout the world and amount of sunlight receive by earth was high every year. This shows that the sun is a major source of inexhaustible free energy to planet earth [1]. The technology to harvesting and collecting solar energy had improved throughout the year. J. Herschel et. al in [2], the first person used a solar thermal collector box that absorbs sunlight to cook food during an expedition to

Africa. Since then, the technology of solar power keeps improving and the latest technology to collect the sunlight is by using photovoltaic panel.

Hydroponics is a crop cultivation method that does not use soil as a growing medium, instead relying on nutrient-rich water or minerals [3]. The term "Hydroponics" comes from the Greek word "Hydroponos," which means "water with power" [4]. Using the hydroponic planting method, farmers can directly carry out and monitor environmental control, nutrition, and water conservation [5]. This hydroponic method can be done vertically in a small space, such as a garden or seating area, involving little space. Hydroponic growing media must meet the following requirements be water absorbent, allow for air circulation and be inexpensive [4].

This paper discusses the development of smart hydroponic system using solar energy as the main supply. The main components are solar panel, inverter with MPPT, lead-acid battery and DC water pump. The hydroponic system uses nutrient film technique (NFT) concept of 40 pieces hygrow-pots and the fertilization system in is automatic based on the monitoring and controlling the ppm value and water level of tank.

2. Hydroponic System and Technology

The hydroponic system is an advanced farming system that does not use soil as the medium. Instead, it uses nutrient water to replace the soil. The use of hydroponic system is very efficient in today's modern world as it uses less water, growing any plants without agriculture farm. Hydroponic can be divided into several systems which are Wick system, Ebb and flow system, Drip system, Deep Water Culture and Nutrient Film Technique (NFT) [5][6][7]. S. Mekhilef *et. al* in [8] discusses the solar energy exploitation in agriculture and this paper focuses on the solar photovoltaic and solar thermal in pumping water, drying crops, cooling the storage and producing heating/cooling greenhouse. Next, M.Dursun *et. al* in [9] discusses solar application in agriculture. In this system, solar energy was used to power up brushless DC motor that was used for water storing in a pool and transferring of water waited in pool to drip irrigation. W. S. W. Abdullah *et. al* in [10], this journal discussing about the potential of using renewable energy in Malaysia especially solar energy. In this M.V. Torshizi *et.al* in [11], this paper discusses the use of solar energy in agriculture system such as to do several farm works, pumping water for irrigation, monitoring system and others. The research found that solar energy technologies for farming is divided into two systems which are photovoltaic cell system and uses solar capture heating system. Fig 1 shows the Nutrient Film Technique (NFT) technique of hydroponic system. NFT technique employs a pump to transport nutrients into a tray of hanging plant roots. The NFT tray differs from the Ebb and Flow tray in that it is slightly inclined to ensure that nutrient water flows back to the reservoir by gravity. Because the NFT is a working device, fresh nutrient water is constantly pushed into the tray.

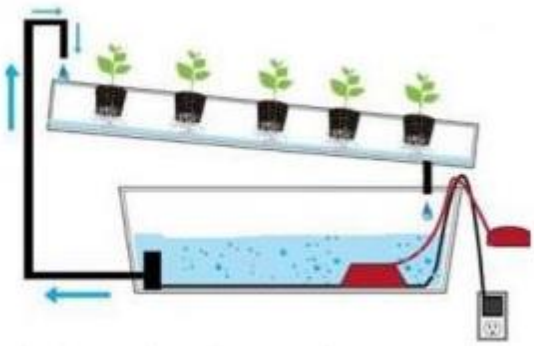

Fig. 1 *NFT Technique of hydroponics system*

In paper [12], Amy Lizbeth *et. al* are developed, calibrated, and validated a monitoring and controlling system for a hydroponic system. To monitor and regulate the pH of nutrient solution in a hydroponic system, an automated monitoring and controlling system was designed. Water culture systems are the systems of leafy lettuce. These are highly costly devices that can be used in locations where there is little or no electric. In the current context, practically everything can be managed and operated automatically; technologies are becoming smarter and more automated, necessitating a revolution in the farming system. The Arduino uno microcontroller may be used to construct a nutritious water flow system, and the sensors can monitor and manage the amount of water in hydroponic tubes [13]. Ullah. A. *et. al* in [14] used an ESP32 microcontroller to control the pump in the suggested system. The pump will pull water from a reservoir connected to a standard water line. If the reservoir's water level goes below a certain level, the system will send an SMS to the Farmer. In paper [15], Keethana *et. al* are developed a sensor, light-emitting diode bulbs, water spray, and a pump capable of successfully decreasing the concentration of dioxide, temperature, and water level. By ensuring that all nutrients are given to the plant via the water solution, the unit area requirements are automatically managed. In paper [16], pH, water level, ambient temperature, and relative humidity are constantly monitored to give the best environment for plant development The irrigation system is managed by water and nutrient input. Sensor data and cloud-based technology may be used as backup to store, manage, apply, and communicate information through the internet. In this project's approach, the Raspberry Pi was used to gather data from the server and send data from the temperature and humidity sensor, pH level sensor, and water level sensor. A water pump was also employed to manage the input of machine water, as well as temperature and humidity sensors to monitor the nutritional conditions of the system.

3. Main Components of Solar PV System

The main component of this research consists of solar panel 405W, 12V 200Ah Lead-Acid Battery and 1200W inverter with MPPT. charger solar controller, rechargeable battery 12V 27AH, as shown in Fig. 2. Table 1 tabulated the parameters od Solar PV panel.

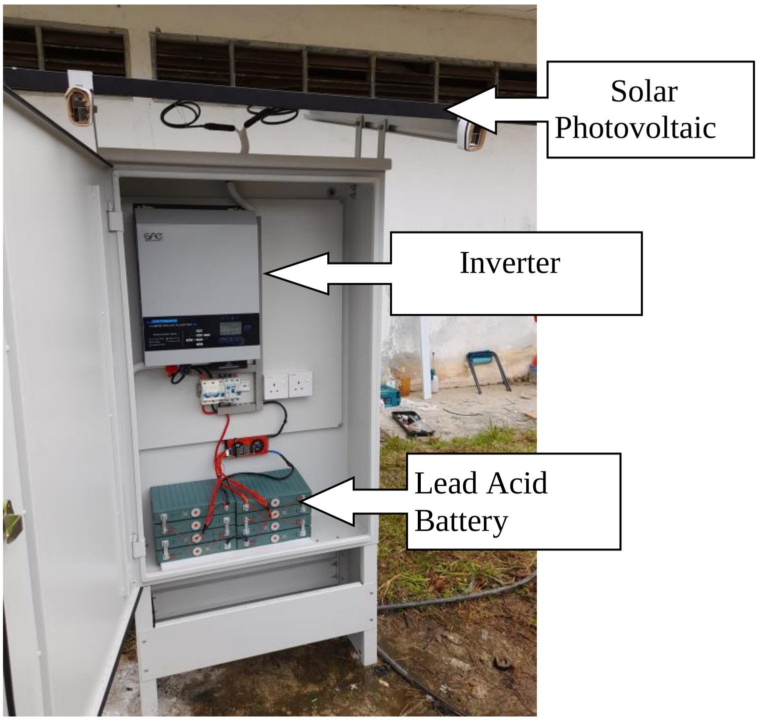

Fig. 2 *The Main Components of Solar PV System*

Table 1 *Parameter of Solar PV Panel 405W*

Parameter	Value [Unit]
Nominal Power (P_{mpp})	405W
Short Circuit Current (I_{sc})	11.19A
Open Circuit Voltage (V_{oc})	45.09V
Current at maximum power (I_{mpp})	10.7A
Voltage at maximum power (Vm_{app})	37.85V
Maximum System Voltage (V_{sys})	1000V

Equation (1) until equation (4) shows the formula for energy consumption to choose the correct sizing of the battery [17][18].

I. Energy Consumption

$$\text{Energy consumption } P(Wh) = \text{Load } (W) \text{ x usage hour (hour)} \quad (1)$$

II. Energy consumption for reserved power including normal days

$$(\text{Operating days} + \text{Reserved days}) \text{ x Energy consumption} \quad (2)$$

III. Battery Capacity

$$Ah = (P(Wh) \,/\, \eta \text{ x DoD x V}) \quad (3)$$

where P(Wh) = Total energy consumption that needs to be supported

η = Efficiency of battery (80%-90%)

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DoD = Depth of Discharge for Battery
V = Voltage of the battery
Ah = Battery capacity (hours)

IV. Battery Charging Time

$$h = (Ah) / A \tag{4}$$

where h = Hours taken for the battery to fully charged,
Ah = Ampere hour rating battery
A = Discharge current battery

Fig. 3 and 4 shows the concept and overall process for the project. A Solar panel is used to capture and convert the solar energy to electrical energy. Then, the electrical energy is stored in battery which is controlled by inverter to avoid overcharging. The inverter is supplying an electricity direct to Arduino board for controlling and monitoring the ppm value and percentage of nutrient level. An automated hydroponic system with a sensor-based fertilizer concentration detection mechanism connected to a nutrient reservoir. Water continuously flows to the plant roots throughout the day.

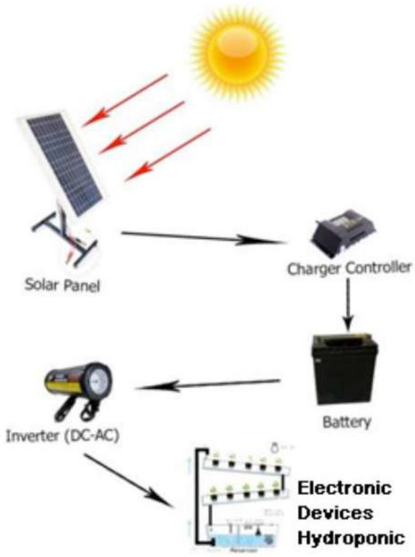

Fig. 3 *The Block diagram of the solar hydroponic System*

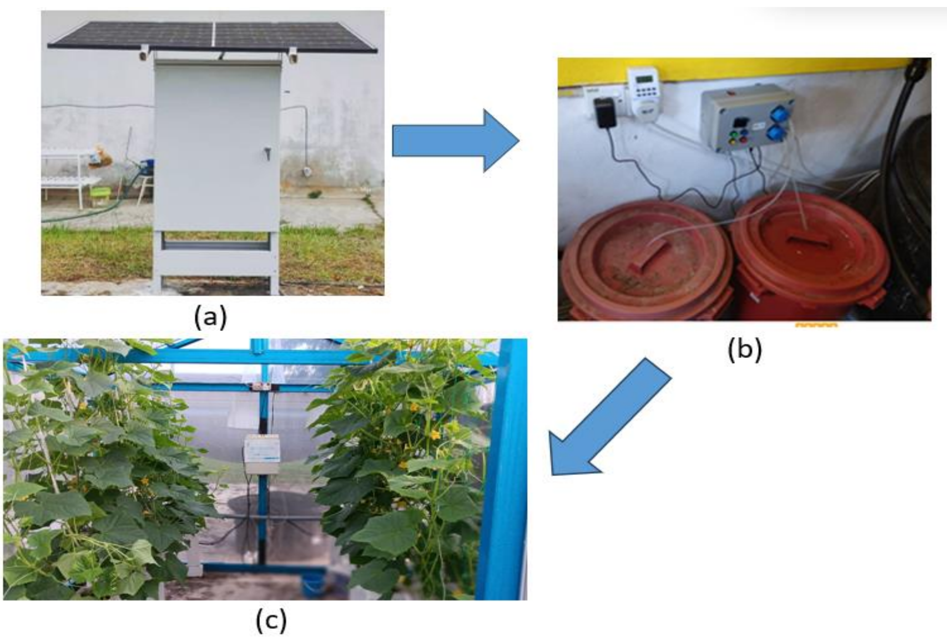

Fig. 4 *(a) Solar PV system, (b) Arduino Board and Mixer Automatic (c)Hydroponic System*

Fig 5 shows the system design of development of solar power automated nutrient composition control and monitoring for hydroponic system. The nutrient mixing and irrigation system will have three 30 litre buckets for water, fertilizer A and B and one 10 litre tank for mixing. Three units of water pumps will be used for fertilizer A, B and irrigation injectors with a flow rate of 350 litre/hour rated at 12 V and two more units used in this system to control water flow to the chosen crops. The flow of the water, fertilizer A and B will be flow correctly into the mixing tank and flow to the hydroponic system [19].

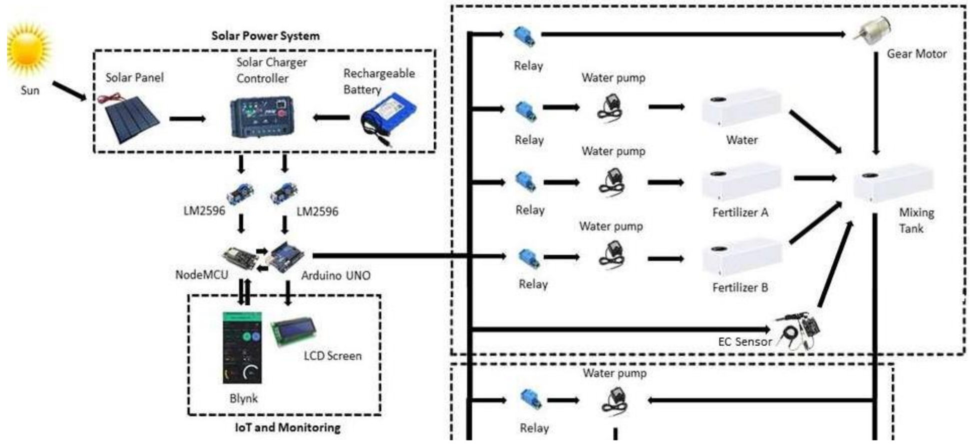

Fig. 5 *Solar Power Automated Nutrient Composition Control for Hydroponic System*

4. Results and Analysis

This section discusses the details of results and analysis of project. The project has been tested twice, namely Case Study I and Case Study II. The duration of each test depends on the growing period of the vegetables until the last day they bear fruit.

(i) Case 1: Conducted from August to December 2023.
(ii) Case 2: Conducted from May to July 2024.

4.1 Case Study I: Tomatoes Cherry and Bell Peppers

Case Study I was tested for five (5) months from August to December 2023 by planting cherry tomatoes and bell peppers until harvesting period. But the collection data at last period in December 2023. The test system at Block E5, University Tun Hussein Onn Malaysia (UTHM).

(a) Tomato Cheery

Cherry tomatoes as shown in Fig 6 or *Solanum lycopersicum var. cerasiforme* are small size, round tomatoes that are a genetic admixture between wild currant-type tomatoes and domesticated garden tomatoes [20]. These tomatoes are valued for their ease of cultivation and versatility in culinary uses. The characteristics of tomatoes cheery are tabulated in Table 2 [21].

(a) **(b)**

Fig. 6 *(a) The Tomato Cheery Plant (b) The Tomato cheery*

Table 2 *The Characteristics of Tomatoes Cheery*

Item	**Value [Unit]**
Botanical name	*Solanum lycopersicum var. cerasiforme*
Family	Solanacea
Plant type	Annual, Fruit
Mature Size	4-6 ft. tall, 1-3 ft. wide
Soil type	Loamy, sandy, moist, well-drained
Soil pH	Acidic (6.0 to 6.5)

(b) Bell Peppers

Bell pepper or capsicum (from Latin: Capsicum) is a group of cultivars of the species Capsicum annuum. These cultivars produce fruits of various colors including red, yellow, orange, green, white, and purple as shown in Fig. 7. Bell peppers are sometimes grouped with less pungent pepper varieties as "sweet peppers." [22]. Table 3 is tabulated by the characteristics is bell peppers [23].

(a) **(b)**

Fig. 7 (a) *The bell pepper Plant (b) The bell peppers*

Table 3 *The Characteristics of Tomatoes Cheery [23]*

Item	Value [Unit]
Botanical name	Capsicum annuum
Family	Solanacea
Plant type	Annual, Fruit
Maximum Size	1,5 m

Fig. 8 shows the results of the ppm (parts per million) value measured using the IoT method and an EC (electrical conductivity) meter. The ppm readings range from 1000 to 1200 during the fruiting period of the plants, which requires a high concentration of fertilizer [24]. These readings were taken from December 1, 2023, to January 6, 2024. The EC meter readings are provided for reference only. Meanwhile, the water percentage readings are around 80% or higher. On December 19, 2023, the water percentage are dropped to 50%, indicating that the water level decreased to half after the system had been operating for 19 days. On the 20th day, water was manually added, raising the water level to 90%.

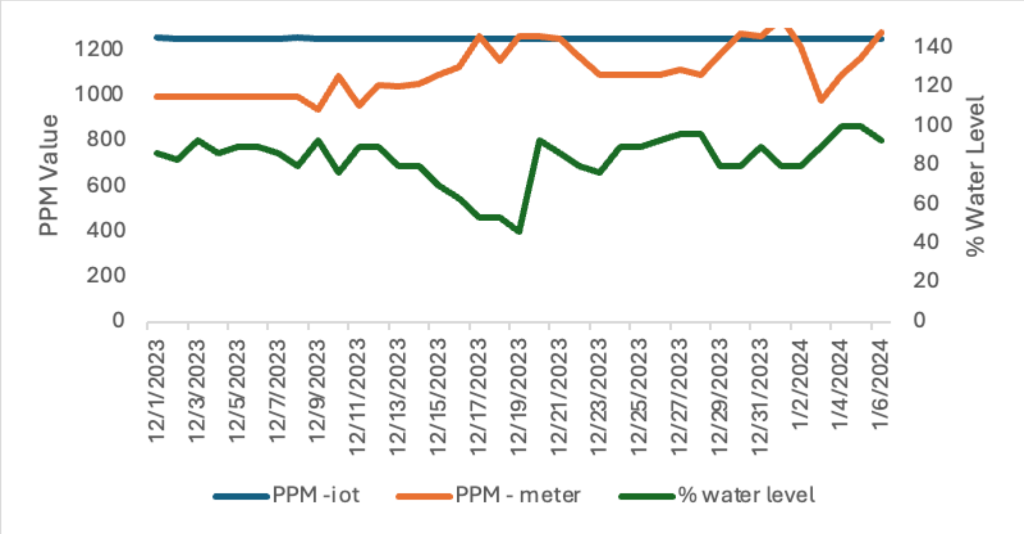

Fig. 8 *The Results of ppm value and percentage of water level for Case Study I*

Fig. 9 shows the output voltage on the PV panel, V_{pv} and the voltage of the battery, V_{batt}. The figure indicates that the voltage ranges from 30V to 40V for V_{PV}. The highest voltage was recorded on 19th and 20th December 2023, at 40V. The lowest V_{pv} was recorded on 7th December 2023, at 26V. Referring to the weather in Batu Pahat, Johor from 5th to 9th December 2023, it was rainy with temperatures around 30°C to 32°C. Meanwhile, 19th and 20th December 2023, experienced sunny and rainy conditions with temperatures around 32°C. This shows that weather and temperature affect the rate of electrical energy generation. The V_{batt} readings are around 26V to 28V, based on the battery specifications. The current readings are directly proportional to the V_{pv}. The highest current was recorded on 13th December 2023, at 6A, while the lowest was 1A on 9th December 2023.

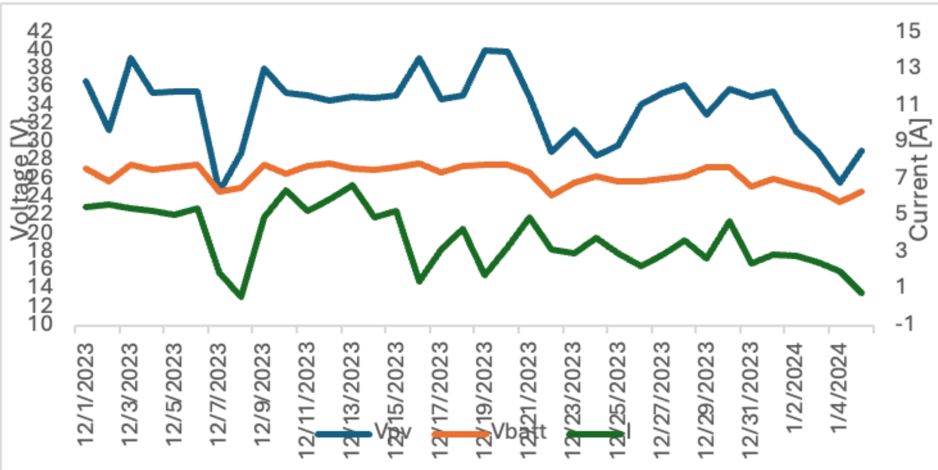

Fig. 9 *Results of V_{pv}, V_{batt} and I of solar system for Case Study I*

4.2 Case Study II: Japanese Cucumber

Case Study II was tested for two (2) months from May to July 202 by planting the Japanese cucumber until harvesting period. The test system is same at Block E5, University Tun Hussein Onn Malaysia (UTHM).
Japanese Cucumber or the specific name is Cucumis sativus Linn has thinner skin and a more pleasant taste compared to regular cucumbers as shown in Fig 10. It has an elongated shape, dark green skin, and a denser, juicier texture than local cucumbers [25]. Table 4 tabulated the characteristic of Japanese cucumber.

(a)

(b)

Fig. 10 *(a) The Japanese cucumber Plant (b) The Japanese Cucumber*

Table 4 *The Characteristics of Japanese Cucumber [23]*

Parameter	Value
Size / length	Small, 20.32cm
Skin	Smooth, dark-green skin
Temperature	18-35°C
pH Land	6 to 7
Nutrients	Nitrogen, Phosphorus, Potassium and Micronutrients

Fig. 11 shows the results of the ppm measured using the IoT method and a measurement value of Japanese cucumber. The ppm readings range 700 during the flowering and increase to 1200 when the fruiting period of the plants, which requires a high concentration of fertilizer [20]. These readings were taken from 20 May until 15 July 2024. The ppm from measurement readings is provided for reference only. Meanwhile, the water percentage readings are around 80% during the Case Study II.

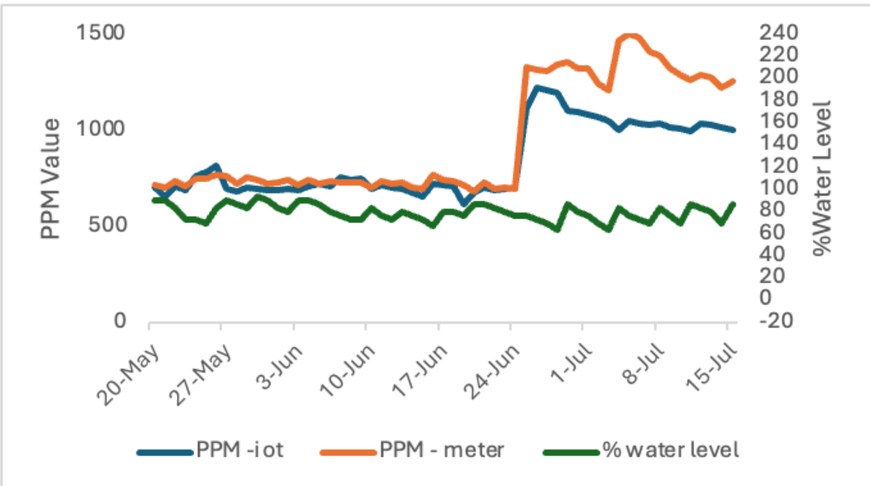

Fig. 11 *The Results of ppm value and percentage of water level for Case Study II*

Fig. 12 shows the output voltage on the PV panel, V_{pv} and the voltage of the battery, V_{batt}. The figure indicates that the voltage ranges from 30V to 40V for V_{PV}. The highest voltage was recorded on 23rd unitl 15th June 2023, at 40V. The lowest V_{pv} was recorded on 16th June , at 30V. Referring to the weather in Batu Pahat, Johor from 20th May until 16th Jun , it was suuny with temperatures average 32°C. Meanwhile, 17th and 30th June 2024, experienced sunny and rainy conditions with temperatures around 30°C. This shows that weather and temperature affect the rate of electrical energy generation. The V_{batt} readings are around 23V to 30V, based on the battery specifications. The current readings are directly proportional to the V_{pv}. The highest current was recorded on 27th May 2024, at 6A, while the lowest was 1A on 20th May 2024.

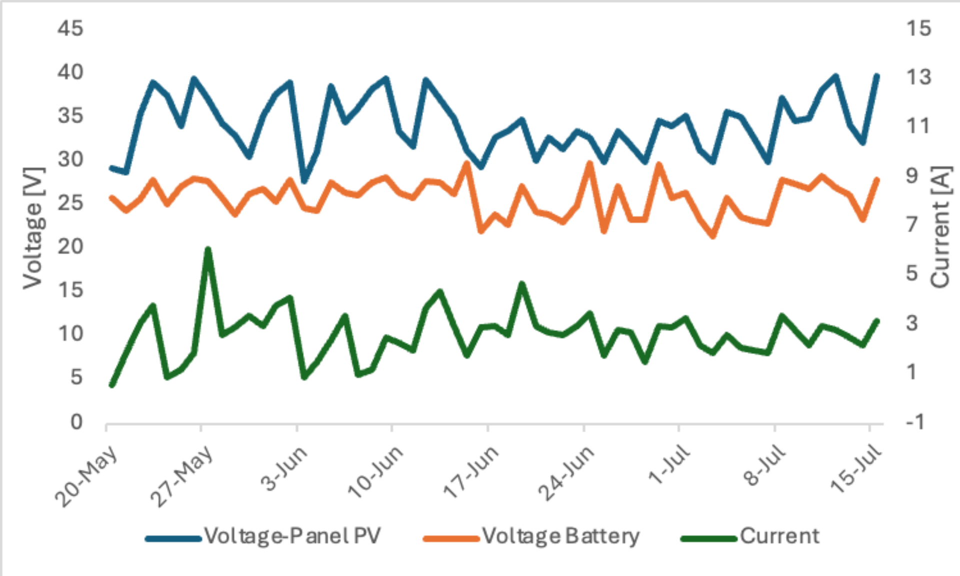

Fig. 12 *Results of V_{pv}, V_{batt} and I of solar system for Case Study II*

5. Conclusion

The project Smart Solar Powered Hydroponic Close- Loop Low-Land Condition was successfully completed and tested twice at the Block E5, UTHM field site. Based on the results obtained, it was found that throughout the test system, the solar PV energy and the automatic mixing systems worked effectively with water and nutrients. The solar PV system successfully supplied electrical power to the DC pump in the water tank, which then distributed water through PVC pipes and continuously powered the automatic fertilizer mixing set. This set was able to be monitoring and controlling the ppm value and percentage of water in the tank.

This project is demonstrating that the project is effectively utilized a green energy as the main power source, automated the fertilization system, and saved both time and the amount of water and fertilizer used for the plants. It is hoped that this project can be applied to larger and commercial agricultural farms in the future.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

This journal requires that all authors take public responsibility for the content of the work submitted for review. The contributions of all authors must be described in the following manner:

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Muhammad Nafis, Ansar, Ahmad Fateh;* ***data collection:*** *Muhammad Syafiq;* ***analysis and interpretation of results:*** *Siti Amely, Ansar;* ***draft manuscript preparation:*** *Siti Amely, Suriana. All authors reviewed the results and approved the final version of the manuscript.*

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