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Lampiran 2

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Monitoring and Controlling of pH Levels and Plant Nutrition Supplied by Standalone Photovoltaic in a Greenhouse Hydroponic System using Arduino Uno

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***Abstract* – This paper aims to implement the prototype model to monitor and control the pH levels and nutrition plant (electrical conductivity-EC) supplied by a standalone photovoltaic (PV) module-connected battery (Lithium-Ion) on the greenhouse hydroponic systems. The two sensors are connected to the Arduino Uno circuit as a relay control to drive four pumps, i.e. the water flow pump, EC pump, pH up pump, and pH down pump. The greenhouse function to control pests and the impact of environmental non-uniformity caused by variation of wind speed, temperature, or sunlight so that hydroponic plants can grow in an appropriate environment. The Arduino Uno circuit with a 20 × 4 liquid crystal display (LCD) order four relays to monitor and control the four pumps of greenhouse hydroponic system based on the coding which has been programmed previously. The prototype model is able to monitor and control the pH of hydroponic plant water at the level between 6-7 using a pH-up and pH-down sensor. This model is also able to monitor and control nutrition plant water over 1 mS/cm using an EC sensor. The proposed prototype is able to monitor and control pH levels between 6-7 and plant nutrients (EC) above 1 mS/cm to maintain plant growth in the hydroponic greenhouse system normal.**

Keywords: Standalone PV, pH, EC, Greenhouse, Hydroponic, Arduino Uno

I. INTRODUCTION

Recently, hydroponics has become a new method of cultivating plants, especially various types of vegetables or fruit, because they do not require large areas of land and can be done in the yard of the house. The hydroponic method uses a solution of mineral nutrients and water without using soil media for the process of growing and maintaining plants. Hydroponic cultivation in greenhouses is now an option to overcome the constraints of cultivating plants in open areas i.e. attack by pests, wind, temperature, and sunlight which sometimes also interfere with the growth and development of vegetable or fruit plants.

The PV module is a source of electrical power to operate the pH control system and the water level of hydroponic plant nutrients until the harvest period has been implemented on [1]. The proposed prototype was able to control the water pH level of 6-7 and the nutrient solution height of 18-20 cm. The pH control and nutrient levels are regulated by a solenoid valve, actuated by a water pump, and the power is supplied by the PV module for 24 hours with varying tilt angles. The electrical conductivity (EC) wireless sensor was supplied by PLN to monitor and control the concentration of the nutrient solution for hydroponic plant cultivation type Nutrient Film Technique (NFT) has been proposed on [2]. The results showed that the EC-meter sensor was able to read the density of the nutrient solution with a relative error percentage of 3.92%. The nutritional control, water temperature, water volume, environmental temperature, pH, and humidity of the hydroponic system are still using the website which has been implemented on [3]. This device was designed to be able to monitor and control the hydroponic system at nutrient temperatures at 23°C-27°C, water height limits 5-10 cm and nutrient levels at the 600-800 ppm limit. The design of PV modules as a power source for DC pump and compared by AC pump to control water flow that supplies nutrients to NFT-type hydroponic plants has been proposed on [4]. This model showed that the use of solar panels and DC pumps to flow water to hydroponic plants is relatively more economical than an AC pump. However, the DC pump was not able to operate continuously, and to overcome this problem then the researchers proposed an AC pump using a DC-AC inverter to drain water in the hydroponic system.

This research will implement the prototype model to monitor and control the pH levels and nutrition plant supplied by a 100 watt-peak (Wp) standalone PV module-connected battery on greenhouse hydroponic systems. The two sensors are connected to the Arduino Uno circuit as a relay control to drive four pumps, i.e. the water flow pump, EC pump, pH up pump, and pH down pump. The greenhouse function to control pests and environmental temperatures so that hydroponic plants can grow in an appropriate environment. The paper is arranged as follows. Chapter II presents the proposed research model, flow chart, PV module concept, greenhouse, Arduino Uno, relay circuit, pH sensor, EC sensor, liquid crystal display (LCD). Chapter III presents the results and discussion i.e. the design of monitoring and control systems for pH and EC levels, measurement and validating the PV and battery module voltages, measurement and validating pH sensor, measurement and validating EC sensor as well as analyzing the performance measurement result of pH sensor and EC sensor in greenhouse hydroponic plant systems. Finally, the paper is concluded in Chapter IV.

II. METHODOLOGY

A. Research Method

The monitoring and control system for pH and EC nutrition in the hydroponic greenhouse prototype consists of a combination of hardware and software. The hardware design consists of a PV module, battery (Lithium-Ion), pH sensor, and EC nutrition sensor combined with Arduino Uno software connected to four relays. These relays function to control the water flow pump, nutrient pump (EC), pH-up pump, and pH-down pump. The block diagram of the proposed model can be seen in Figure 1.

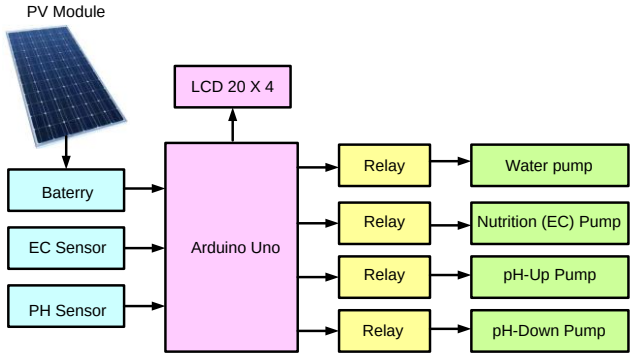


Figure 1. Proposed reseach model

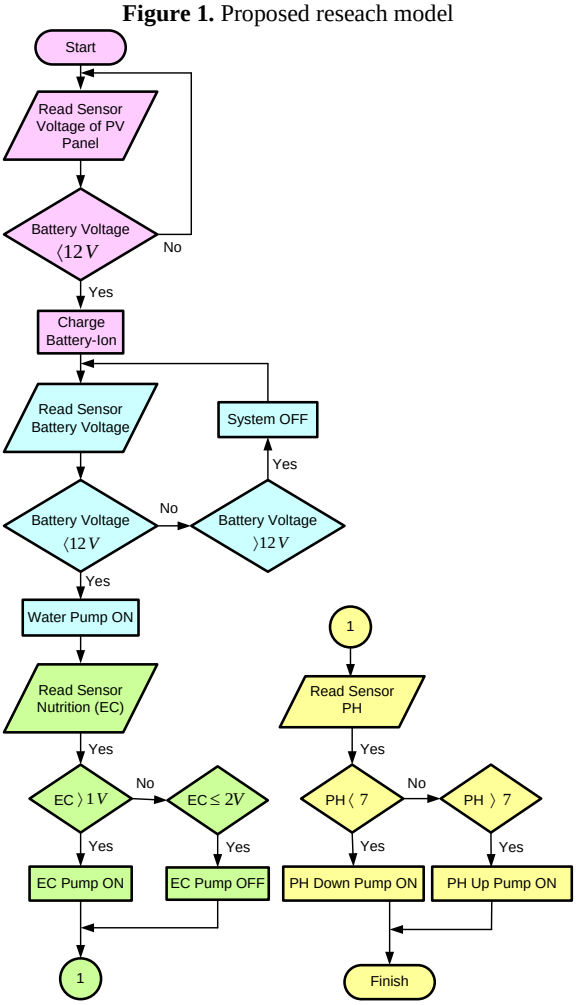


Figure 2. Research flowcart

Figure 1 shows the proposed research model. The 100 Wp standalone photovoltaic (PV) module charges the battery (Lithium-Ion). After the battery is fully charged, the EC sensor and PH sensor will work. The Arduino Uno circuit with a 20 × 4 LCD display will then order four relays i.e. water flow pump, nutrient (EC) pump, pH-up pump, and pH-down pump to work to control the hydroponic system in a greenhouse based on the coding which has been written previously on Arduino-Uno. Figure 2 shows the research flowchart. The research starts with the sensor reading the PV module output voltage. If the battery voltage is less than 12 V, the PV power will charge previously the battery. Then, the battery voltage sensor will work logically if the battery voltage is less than 12 V, then the water flow pump will work. Whereas if the battery voltage exceeds 12 V, the system will shut down. After the water pump starts, the nutrition sensor (EC) will work logically if the EC voltage is greater than 1 then the EC pump will turn on and if the EC voltage is less than 2 then the EC pump will shut down. Furthermore, the pH sensor works to monitor the pH level of the water. If the pH level is below 7 then the PH pump down will work (On), conversely, if the pH level is above 7 then the pH up pump will work (On).

B. Modelling Photovoltaic

The equivalent circuit of PV is shown in Figure 3. It consists of several PV cells which have external connections in series, parallel, or series-parallel [5].

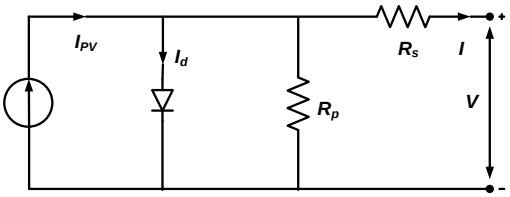


Figure 3. Equivalent circuit of PV panel

The V-I characteristic is shown in Eq. (1):

$$I = I_{PV} - I_o \left[exp\left(\frac{V+R_S I}{a\, V_t}\right) - 1 \right] - \frac{V+R_S I}{R_P} \qquad (1)$$

Where I_{PV} is PV current, I_o is saturated re-serve current, 'a' is the ideal diode constant, $Vt = N_S K T q^{-1}$ is the thermal voltage, N_S is a number of series cells, q is the electron charge, K is Boltzmann constant, T is temperature pn junction, R_S and R_P are series and parallel resistance of solar panels. I_{PV} has a linear relationship with light intensity and also varies with temperature variations. I_o is a dependent value on the temperature variation. Eq. (2) and Eq. (3) are the calculation of I_{PV} and I_o values:

$$I_{PV} = \left(I_{PV,n} + K_I \Delta T\right) \frac{G}{G_n} \qquad (2)$$

$$I_o = \frac{I_{SC,n} + K_I \Delta T}{exp\,(V_{OC,n} + K_V \Delta T)/aV_t - 1} \qquad (3)$$

Where $I_{PV,n}$, $I_{SC,n}$, and $V_{OC,n}$ are the photovoltaic current, short circuit current, and open-circuit voltage under standard conditions ($T_n = 25^0 C$ and $G_n = 1000\, W/m^2$), respectively. The K_I value is the coefficient of short circuit current to temperature, $\Delta T = T - T_n$ is temperature deviation from standard

temperature, G is the light intensity and K_V is coefficient of open-circuit voltage ratio to temperature. Open circuit voltage, short circuit current, and voltage-current related to maximum power are three important values of I-V characteristics of PV panel. These points are changed by variation in atmospheric conditions. By using Eq. (4) and Eq. (5) derived from the PV model equation, short-circuit current and open-circuit voltage can be calculated under different atmospheric conditions.

$$I_{SC} = (I_{SC} + K_I \Delta T)\frac{G}{G_n} \quad (4)$$

$$V_{OC} = (V_{OC} + K_V \Delta T) \quad (5)$$

C. Green House

The greenhouse is a frame or corrugated building covered with a clear or translucent material that can transmit light optimally for production and protect plants from climatic conditions that are detrimental to plant growth. The cultivating of plants in a greenhouse has the advantage of a more controlled microenvironment and uniformity of production for each plant. The functions of a greenhouse include managing plant growth schedules, increasing production yields, minimizing pesticides, increasing production quality, assets, and performance, as well as a means of agro-tourism [6].

D. Arduino Uno

Arduino-Uno is an electronic board containing an ATMega328 microcontroller, which is a chip that functionally acts like a computer. This device is used to realize electronic circuits from simple to complex. LED control to robot control can be used. implemented using this relatively small board. In the health sector with the addition of certain components, this tool can be used to monitor the condition of patients in the hospital and control equipment at home [7]. Figure 4 shows the Arduino Uno model.

Figure 4. Arduino Uno model

E. Relay Circuit

The relay circuit is a link between the Arduino Uno circuit with the water flow pump, nutrient pump (EC), pH-up pump, and pH-down pump to work on controlling the greenhouse hydroponic system based on the coding previously programmed on Arduino-Nano. Figure 5 shows a relay circuit on the greenhouse hydroponic system.

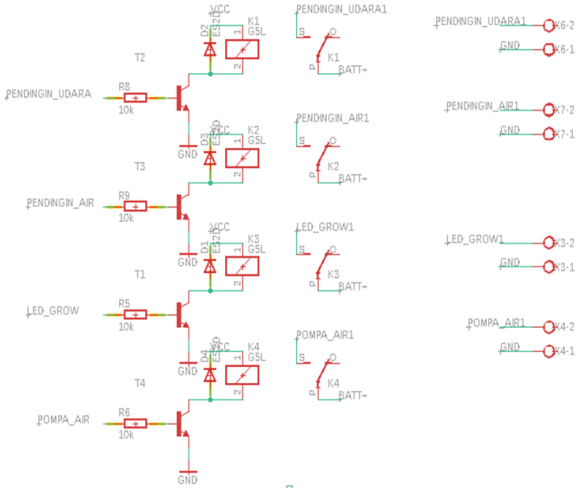


Figure 5. Relay circuit

F. Sensor Electrical Conductivity

The Electrical Conductivity (EC) sensor is used to measure the concentration of a solution for example hydroponic nutrient solution which is expressed in units of miliSiemens per centimeter (mS/cm). The EC-meter is an alternative measurement device to the Total Dissolved Solids (TDS)-meter to measure the concentration of a hydroponic nutrient solution expressed in units of parts per million (ppm) [8]. The EC value affects the rate of nutrition absorption by plants, the greater the EC value, the faster the absorption of nutrition by plants and vice versa if the EC value is smaller, the absorption of nutrition will be slow [9]. The series of EC sensors installed in the greenhouse hydroponic system is connected to the Arduino-Uno, using the IDE software and libraries in the Arduino Uno. Figure 6 shows the EC sensor circuit.

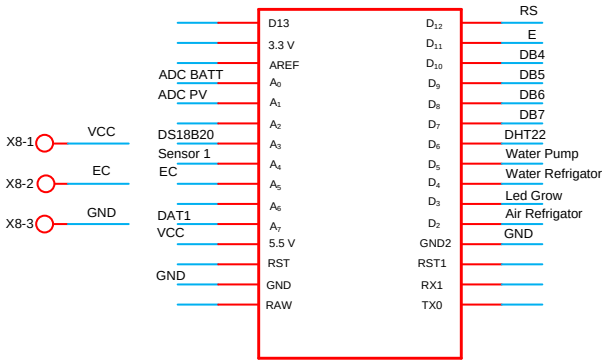


Figure 6. EC sensor circuit

G. Sensor pH

The pH sensor is an instrument for measuring the concentration of hydrogen in a solution. The pH sensors for water and for soil need to be calibrated periodically so that the accuracy of the measurement is guaranteed. The series of pH sensors installed in the greenhouse hydroponic system is connected to the Arduino-Uno, using the IDE software and libraries in the Arduino Uno. The pH sensor circuit is shown in Figure 7.

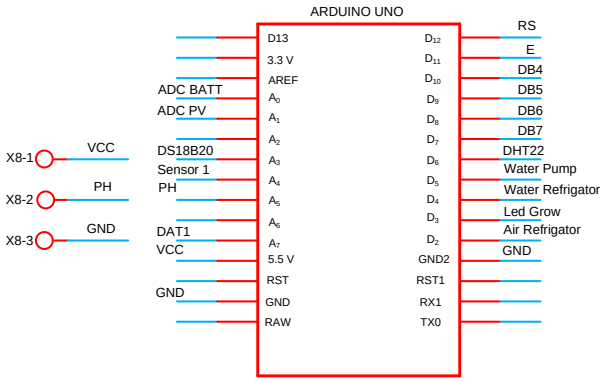


Figure 7. The pH sensor circuit

H. Liquid Crystal Display

Liquid Crystal Display (LCD) is a type of display media that uses liquid crystals as the main display. LCD has been used in various fields, for example in electronic devices, such as televisions, calculators, or computer screens. The LCD circuit that is installed with a greenhouse hydroponic is connected to the Arduino-Uno, using the IDE software and libraries in the Arduino Uno. Figure 8 shows the LCD circuit.

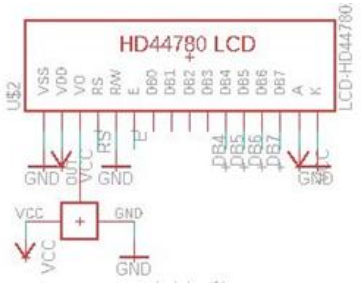
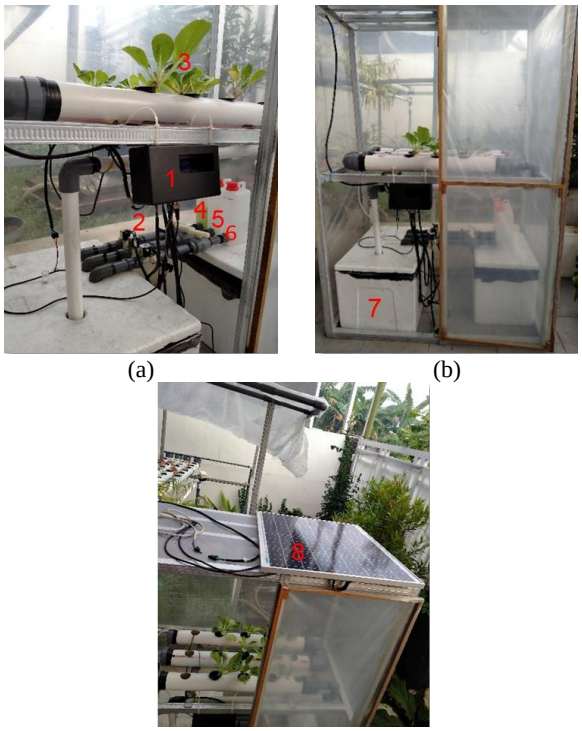


Figure 8. LCD circuit

III. RESULTS AND DISCUSSION

Figure 9 shows the implementation of a monitoring system for pH and plant nutrition in a greenhouse hydroponic system using Arduino Uno. Figure 7.a shows (1) Arduino-Uno Controller, (2) Solenoid Valve, (3) Hydroponic Plant, (4) Nutrition EC, (5) pH-up, and (6) pH-down. Figure 7.b. shows nutrient water and sensors. Figure 7.c shows the PV module connected to a battery (Lithium-Ion). The working mechanism of this prototype is started by the sensors read the output voltage of the PV module. If the battery voltage is less than 12 V, the PV output power will charge the battery. In this condition, the battery voltage sensor will work and the water pump will also work. After the water pump starts then the EC sensor also works, with logic if the EC level is greater than 1 then the EC pump will turn on and if the EC level is less than 2 then the EC pump will shut down. Furthermore, the pH sensor works to monitor the PH level of the water. If the PH level is below 7 then the PH-down pump will work (On), otherwise if the pH level is above 7 then the pH-up pump will work (On). To obtain better monitoring and control system performance, a number of validation measurements are carried out i.e. PV voltage, battery voltage, EC sensor, and pH sensor.



(a) (b)

(c)

Figure 9. Implementation of a monitoring system for pH and plant nutrition in a greenhouse hydroponic system

Table 1. Measurement of PV voltage

No.	Volt Meter (V)	Sensor Tegangan PV (V)	Error (%)
1	5.00	5.07	1.400
2	7.00	7.10	1.429
3	9.00	9.09	1.000
4	12.00	12.08	0.667

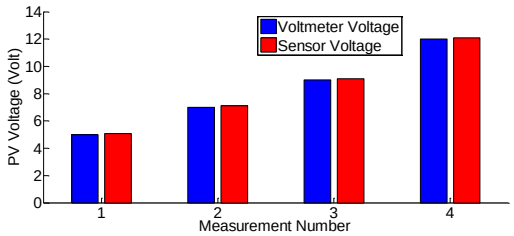


Figure 9. Measurement of PV voltage

Table 1 and Figure 9 show the PV voltage measurement using a voltmeter and a PV voltage sensor. The first measurement with a voltmeter produces a PV voltage of 5 V, while the measurement uses a sensor as 5.07 V. The fourth measurement with a voltmeter produces a PV voltage of 12 V, while the measurement uses a sensor as 12.08 V. The four measurement results show that the PV voltage sensor produces a measurement accuracy close to the same compared to measurements using a voltmeter with a maximum error of 1.429% or already below 5%.

Table 2 and Figure 10 show the battery voltage measurement using a voltmeter and a battery voltage sensor. The first measurement with a voltmeter produces a PV voltage of 5 V, while the measurement using a sensor resulting of 5.10 V. The fourth measurement with a voltmeter produces a PV voltage of 12 V, while the measurement using a sensor resulting of 12.07 V.

Table 2. Measurement of battery voltage

No.	Volt Meter (V)	Sensor Tegangan Baterai (V)	Error (%)
1	5.00	5.10	2.000
2	7.00	7.06	0.857
3	9.00	9.09	1.000
4	12.00	12.07	0.583

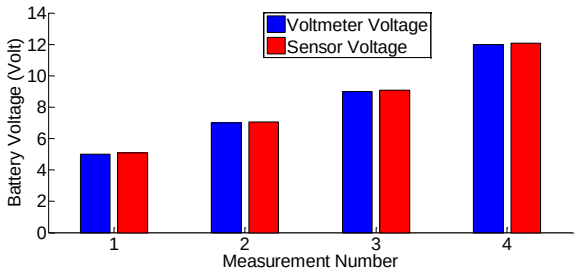


Figure 10. Measurement of battery voltage

The four measurements show that the battery voltage sensor produces a measurement accuracy close to the same compared to measurements using a battery with a maximum error of 2% or already below 5%. PH sensor measurements are carried out to ensure the sensor can run properly because it can affect pH measurements when monitoring equipment is applied to hydroponic plants in greenhouses. Figure 11 shows pH measurements using a digital pH-meter. Figure 12 shows pH measurements using a pH sensor. Table 3 shows the measurements of water pH using a digital pH meter and pH sensor. Figure 13 shows the comparison of the pH of the water using a digital-meter and sensor.

Figure 11. pH measurement using digital-meter

Figure 12. pH measurement using sensor

Table 3 Measurements of water pH using a digital pH meter and pH sensor

No.	PH air	Digital PH meter	Sensor PH	Error (%)
1	4.00	4.0	4.33	8.250
2	6.86	6.8	6.76	1.458

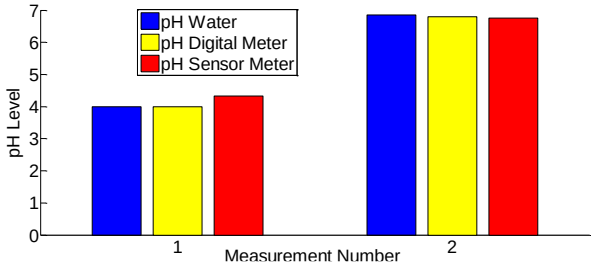


Figure 13. Comparison of the pH water using a digital-meter and sensor

Table 3 and Figure 13 show that on measurement 1 the pH value of water is 4, read by digital pH meter and pH sensor of 4.0 and 4.33, respectively. Meanwhile, measurement 2 shows that the pH value of the water is 6.86, which is read by a digital pH meter and a pH sensor of 6.8 and 6.76, respectively. Table 3 shows that measurements using a digital pH meter and a pH sensor are able to give close to the same results. The measurement results of pH sensors with water pH below 6 are still inaccurate because they produce an error of 8.250%. However, the measurement of pH sensors with water pH values between 6-7 is relatively accurate because it produces an error of 1.458% or is already below 5%. EC sensor measurements are carried out to ensure the nutrient sensor is functioning properly, because this indicator will affect the EC measurement of the water when the monitoring system is running. Table 4 shows the measurement of nutrition levels using the TDS sensor and the EC sensor.

Table 4. Nutrition measurement using TDS and EC sensors

No.	Digital TDS (ppm)	Sensor TDS (ppm)	Sensor EC (mS/cm)
1	450	458	1.23
2	540	542	1.45
3	760	765	2.05
4	880	882	2.30

The performance measurement of the pH monitoring system is carried out to ensure that the pH of the water can be controlled to a degree of acidity between 6-7. This range of values is needed to keep hydroponic plant growth relatively stable. Measurements are made on a hydroponic plant monitoring system, using a relay that functions to run the pH pump motor. The function of pH-Up and pH-Down is to keep the pH of hydroponic plant water at the level of 6-7. Table 5 shows the performance measurements of the pH sensor. Figure 14 shows the measurement of pH-Up performance at 08.00 and 14.00 hours.

Table 5. Performance measurement using pH sensor

Hours	Sensor pH	pH-Up	pH Down
08.00	4.33	On	Off
10.00	6.45	Off	Off
12.00	6.76	Off	Off
14.00	7.32	Off	On
16.00	6.47	Off	Off

Figure 14. Performance measurement of pH-Up at 08.00 and 14.00 hours

Table 5 and Figure 14 show that at 08.00 the pH level is below 6 so that the pH-Up sensor is on. In this condition, the solenoid valve will open to drain pH-Up water so that the pH value rises to above 6. On the other hand, at 10.00, 12.00, 14.00, and 16.00 the pH level is above 6 so that the pH-Up sensor is in the Off status. Table 5 and Figure 6 also show that at 14.00 hours the pH level is above 7 so that the pH-down sensor is On. In this condition, the solenoid valve will open to drain pH-down water to lower the pH value to below 7. On the other hand, at 08.00, 10.00, 12.00, and 16.00 hours the pH level are already below 7 so that the pH-down sensor is automatically in the Off status.

The performance measurement of EC is carried out to ensure that the water nutrition concentration can be controlled within a value range of 1-2 mS/cm. The EC control is needed to keep hydroponic plant growth relatively stable. The measurements are made on the hydroponic plant monitoring system, using a relay that functions to run the EC pump motor. Table 6 shows the performance measurements using an EC sensor. Figure 15 shows the measurement of EC at 08.00 and 16.00 hours.

Table 6. Performance measurements using EC sensor

Jam	Sensor EC	EC-Up
08.00	0.59	On
10.00	1.45	Off
12.00	1.28	Off
14.00	1.32	Off
16.00	1.30	Off

Gambar 16. Performance measurement of EC sensor at 08.00 and 16.00 hours

Table 6 and Figure 16 show that at 08.00 hours the level of EC nutrition is still below 1 so that the EC-Up sensor is On. In this condition, the solenoid valve will open to drain EC water and raise the pH level to above 1. On the other hand, at 10.00, 12.00, 14,000, and 16.00 the EC nutrient level is already above 1 so that the EC-Up sensor is automatically in the Off status.

IV. CONCLUSION

The prototype model to monitor and control the pH levels and EC nutrition plant supplied by a standalone PV module-connected battery on greenhouse hydroponic systems has been implemented. The two sensors are connected to the Arduino Uno and relay control to drive four pumps, i.e. the water flow pump, EC pump, pH up pump, and pH down pump. The prototype model is able to monitor and control the pH of hydroponic plant water at the level between 6-7 using pH-up and pH-down sensor. This model is also able to monitor and control nutrition plant water over 1 mS/cm using EC sensor. The implementation of the EC sensor is only able to control the EC value if the value is less than 1 mS/cm. On the other hand, optimal plant growth in a hydroponic greenhouse system requires controlled EC values between 1-2 mS/cm. The use of an EC-down sensor to control the EC value so as not to exceed the 2 mS/cm value is proposed as future work to overcome this problem.

ACKNOWLEDGEMENT

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Lampiran 2.2

Hasil review makalah dari

Reviewer pertama

ELKHA: Jurnal Teknik Elektro
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PEER-REVIEW REPORT
(Reviewer Number: RV1.)

Note: For comments/questions/Answer/Revisions, use the language according to the language used in the manuscript (English or Bahasa Indonesia).

Reviewer Recommendation: ~~**Accepted**~~**/ Accepted with Minor Revisions /** ~~**Major Revisions**~~ **/** ~~**Rejected**~~
(Please choose one, and delete the others. If you reject the manuscript, please give strong arguments in the comments)

I. Manuscript Identity

Title	Monitoring and Controlling of pH Levels and Plant Nutrition Supplied by Standalone Photovoltaic in a Greenhouse Hydroponic System using Arduino Uno
Manuscript number	45657
Article Type	Research article / ~~Review Article~~
First Submission date	2021-03-15

II. Reviewer's Comments

2.1. General Impression

(For the reviewer: please look Manuscript as a whole, and please give the following Comments)

	Comments
General comprehension of the manuscript	This paper presents an approach to monitor and control pH levels (6-7) and plant nutrition supplied.
Language/style/ Grammar in general	It is good; however, it is required to be improved to increase the readability.
Structure	Good and understandable. It has followed ELKHA's template.
Level of enthusiasm	Medium. In the implementation, the paper sounds nice to read. The novelty needs to be explained explicitly to give a confidence to the readers that this paper coveys a new approach or idea on controlling pH dan nutrition supplied.

2.2. Major Comments to the Authors

(For the reviewer: Please be specific to help the author to do the right revision. Major comments related to the substantial matter).

	Reviewer **Major Comments/Questions**
Abstract	1. The Abstract has been summarizing the paper including the key results. 2. The grammar of some sentences, required to be improved to increase the readability. For instance, *"The Arduino Uno circuit with a 20 × 4 liquid crystal display (LCD) order four relays to monitor and control the four pumps of greenhouse hydroponic system based on the coding which has been programmed previously.",* somehow can misinterpreted, the word "order" should be replaced with other word, depending on its true meaning. Check other sentences too, to make sure it contains readability sentence and no unnecessary information.
Introduction	3. The explanation is well organized and effective, however need to be clearer. The author only gives the drawback on approach in [4], the author

	should also explain the drawback approaches in [1]-[3], to increase confidence of the readers, that the proposed approach gives a level of novelty. 4. Add more citations in this section, it will increase the quality of the paper. 5. The last paragraph has already try to explain what is proposed in this paper, but it is better not the technical, but the concept which is novel and different with the previous approach. The technical terms can be added, but the details should be written in methodology and results and discussion section.
Methodology	5. Overall, the methodology is particularly good and easy to follow. It is better there one sentence or more saying ''as a statement' what the new method proposed which is different with previous approaches. This will increase citation to your paper once it is published.
Results and Discussion	5. The results documentation is quite convincing in terms of implementation. 6. I think there are some typos in Section III praragraph 1, in the second till fourth sentence. Instead Figure 7.a, 7.b., and 7.c., It should be Figure 9a, 9b, dan 9c. 7. The first sentence in the second paragraph, I think it should be Figure 10, the Figure number also should be 10, since there are two Figure 9. 8. The standard error or error tolerance required for the system must be mentioned for each measurement, shown in the tables and their explanation. 9. For easy to read, there should be space between figures, tables, and sentences.
Conclusions	10. The conclusion is good. One thing to be added is what is the key results, and is it solve the problem or better than the previous approach. This statement is important to give a level of confidence for the readers to cite the paper.

2.3. Minor Comments to the Authors

(For the reviewer: Please be specific to help the author to do the right revision. Minor comments related to small failures such as typo, blurred Figures, etc.).

	Reviewer **Minor Comments/Questions**
Style/Grammar	1. Good, Improve the presentation of your paper (style/grammar) with the help of the language tools or other person that has a very good English capability, since once your paper published, it will be read by the people in the world. Therefore, the good presentation can make them to have a will to read the paper, or even cite it and collaborate with the author.
Consistency/Terminology	2. Good
References	3. Follow the template. Some list has a shadow background, check it.
Tables	4. Some tables has no space or even has big space with the Figure or sentence close to it, Give an appropriate space between them. 5. The tables format has not following the ELKHA's template, revise them.
Figures	6. There are two Figure 9 in Section III. 7. Some figures has no space or even has big space with the Figure or sentence close to it, Give an appropriate space between them.

2.4. Overall Comments to the Authors

	Comments
Originality: New or Novel contribution	~~Strong Accept~~ / Weak Accept / ~~neutral / Weak Reject / Reject / Strong Reject~~ *(please choose only one)*
Significance of Topic: Relating to knowledge contribution	Strong Accept / ~~Weak Accept / neutral / Weak Reject / Reject / Strong Reject~~ *(please choose only one)*
Presentation: Clarity and Organisation of Content	~~Strong Accept~~ / Weak Accept / ~~neutral / Weak Reject / Reject / Strong Reject~~ *(please choose only one)*
Reviewer Expertise: Define your (reviewer) expertise on subject of the paper.	Expert / ~~Familiar / Working Knowledge / Some Knowledge /Basic Knowledge~~ *(please choose only one)*

2.5. Comments to the Editors

	Comments
Is there a financial or other conflict of interest between your work and that of the authors?	**~~Yes~~ / No**
Please give comments of the strengths and weaknesses of the article to accept/reject the manuscript:	**This paper can be considered to be published in ELKHA after revising it based on the comments that I have been providing.**

Lampiran 2.3

Hasil review makalah dari

Reviewer kedua

ELKHA: Jurnal Teknik Elektro
ISSN (Print): 1858-1463, ISSN (on-line): 2580-6807
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PEER-REVIEW REPORT
(Reviewer Number: RV2.)

Note: For comments/questions/Answer/Revisions, use the language according to the language used in the manuscript (English or Bahasa Indonesia).

Reviewer Recommendation: **Accepted/ Accepted with Minor Revisions / Major Revisions / Rejected**
(Please choose one, and delete the others. If you reject the manuscript, please give strong arguments in the comments)

I. Manuscript Identity

Title	Monitoring and Controlling of pH Levels and Plant Nutrition Supplied by Standalone Photovoltaic in a Greenhouse Hydroponic System using Arduino Uno
Manuscript number	45657
Article Type	Research article / ~~Review Article~~
First Submission date	2021-03-15

II. Reviewer's Comments

2.1. General Impression

(For the reviewer: please look Manuscript as a whole, and please give the following Comments)

	Comments
General comprehension of the manuscript	Makalah ini membahas tentang pengendalian pH dan nutrisi pada tanaman hidroponik, hanya untuk judul terlalu Panjang akan lebih bagus dapat disingkat.
Language/style/ Grammar in general	Baik, hanya masih terdapat kalimat salah ketik
Structure	Baik
Level of enthusiasm	Baik

2.2. Major Comments to the Authors

(For the reviewer: Please be specific to help the author to do the right revision. Major comments related to the substantial matter).

	Reviewer
	Major Comments/Questions
Abstract	Sudah terdapat abstrak, hanya perlu perbaikan pada kalimat yang sama dengan kesimpulan.
Introduction	Terdapat penjelasan yang kurang (lihat lampiran)
Methodology	Pada Flowchart perlu dicek kembali, ada pembahasan yang tidak nyambung dengan judul.
Results and Discussion	Cek kembali penomoran gambar.
Conclusions	Kalimat copy paste dari abstrak…untuk di cek kembali

2.3. Minor Comments to the Authors

(For the reviewer: Please be specific to help the author to do the right revision. Minor comments related to small failures such as typo, blurred Figures, etc.).

	Reviewer
	Minor Comments/Questions
Style/Grammar	
Consistency/Terminology	
References	
Tables	Format tabel cek kembali, sesuaikan dengan template jurnal ELKHA
Figures	Terdapat gambar yang kurang jelas, kabur.

2.4. Overall Comments to the Authors

	Comments
***Originality*:** New or Novel contribution	Strong Accept / **Weak Accept** / neutral / Weak Reject / Reject / Strong Reject *(please choose only one)*
***Significance of Topic*:** Relating to knowledge contribution	**Strong Accept** / Weak Accept / neutral / Weak Reject / Reject / Strong Reject *(please choose only one)*
***Presentation*:** Clarity and Organisation of Content	**Strong Accept** / Weak Accept / neutral / Weak Reject / Reject / Strong Reject *(please choose only one)*
***Reviewer Expertise*:** Define your (reviewer) expertise on subject of the paper.	Expert / **Familiar** / Working Knowledge / Some Knowledge /Basic Knowledge *(please choose only one)*

2.5. Comments to the Editors

	Comments
Is there a financial or other conflict of interest between your work and that of the authors?	**No**
Please give comments of the strengths and weaknesses of the article to accept/reject the manuscript:	**Naskah ini perlu sedikit perbaikan untuk dapat diterima dan diterbitkan.**

ELKHA : *Jurnal Teknik Elektro, Vol. xx No.yy., Month 20xx, pp. 1-2*
ISSN: 1858-1463 (print), 2580-6807 (online)

Monitoring and Controlling of pH Levels and Plant Nutrition Supplied by Standalone Photovoltaic in a Greenhouse Hydroponic System using Arduino Uno

Abstract **– This paper aims to implement the prototype model to monitor and control the pH levels and nutrition plant (electrical conductivity-EC) supplied by a standalone photovoltaic (PV) module-connected battery (Lithium-Ion) on the greenhouse hydroponic systems. The two sensors are connected to the Arduino Uno circuit as a relay control to drive four pumps, i.e. the water flow pump, EC pump, pH up pump, and pH down pump. The greenhouse function to control pests and the impact of environmental non-uniformity caused by variation of wind speed, temperature, or sunlight so that hydroponic plants can grow in an appropriate environment. The Arduino Uno circuit with a 20 × 4 liquid crystal display (LCD) order four relays to monitor and control the four pumps of greenhouse hydroponic system based on the coding which has been programmed previously. The prototype model is able to monitor and control the pH of hydroponic plant water at the level between 6-7 using a pH-up and pH-down sensor. This model is also able to monitor and control nutrition plant water over 1 mS/cm using an EC sensor. The proposed prototype is able to monitor and control pH levels between 6-7 and plant nutrients (EC) above 1 mS/cm to maintain plant growth in the hydroponic greenhouse system normal.**

Keywords: Standalone PV, pH, EC, Greenhouse, Hydroponic, Arduino Uno

I. INTRODUCTION

Recently, hydroponics has become a new method of cultivating plants, especially various types of vegetables or fruit, because they do not require large areas of land and can be done in the yard of the house. The hydroponic method uses a solution of mineral nutrients and water without using soil media for the process of growing and maintaining plants. Hydroponic cultivation in greenhouses is now an option to overcome the constraints of cultivating plants in open areas i.e. attack by pests, wind, temperature, and sunlight which sometimes also interfere with the growth and development of vegetable or fruit plants.

The PV module is a source of electrical power to operate the pH control system and the water level of hydroponic plant nutrients until the harvest period has been implemented on [1]. The proposed prototype was able to control the water pH level of 6-7 and the nutrient solution height of 18-20 cm. The pH control and nutrient levels are regulated by a solenoid valve, actuated by a water pump, and the power is supplied by the PV module for 24 hours with varying tilt angles. The electrical conductivity (EC) wireless sensor was supplied by PLN to monitor and control the concentration of the nutrient solution for hydroponic plant cultivation type Nutrient Film Technique (NFT) has been proposed on [2]. The results showed that the EC-meter sensor was able to read the density of the nutrient solution with a relative error percentage of 3.92%. The nutritional control, water temperature, water volume, environmental temperature, pH, and humidity of the hydroponic system are still using the website which has been implemented on [3]. This device was designed to be able to monitor and control the hydroponic system at nutrient temperatures at 23°C-27°C, water height limits 5-10 cm and nutrient levels at the 600-800 ppm limit. The design of PV modules as a power source for DC pump and compared by AC pump to control water flow that supplies nutrients to NFT-type hydroponic plants has been proposed on [4]. This model showed that the use of solar panels and DC pumps to flow water to hydroponic plants is relatively more economical than an AC pump. However, the DC pump was not able to operate continuously, and to overcome this problem then the researchers proposed an AC pump using a DC-AC inverter to drain water in the hydroponic system.

This research will implement the prototype model to monitor and control the pH levels and nutrition plant supplied by a 100 watt-peak (Wp) standalone PV module-connected battery on greenhouse hydroponic systems. The two sensors are connected to the Arduino Uno circuit as a relay control to drive four pumps, i.e. the water flow pump, EC pump, pH up pump, and pH down pump. The greenhouse function to control pests and environmental temperatures so that hydroponic plants can grow in an appropriate environment. The paper is arranged as follows. Chapter II presents the proposed research model, flow chart, PV module concept, greenhouse, Arduino Uno, relay circuit, pH sensor, EC sensor, liquid crystal display (LCD). Chapter III presents the results and discussion i.e. the design of monitoring and control systems for pH and EC levels, measurement and validating the PV and battery module voltages, measurement and validating pH sensor, measurement and validating EC sensor as well as analyzing the performance measurement result of pH sensor and EC sensor in greenhouse hydroponic plant systems. Finally, the paper is concluded in Chapter IV.

II. METHODOLOGY

A. Research Method

The monitoring and control system for pH and EC nutrition in the hydroponic greenhouse prototype consists of a combination of hardware and software. The hardware design consists of a PV module, battery (Lithium-Ion), pH sensor, and EC nutrition sensor combined with Arduino Uno software connected to four relays. These relays function to control the water flow pump, nutrient pump (EC), pH-up pump, and pH-down pump. The block diagram of the proposed model can be seen in Figure 1.

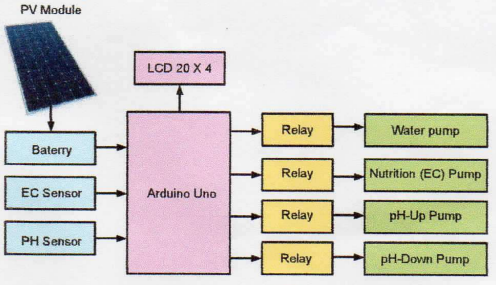

Figure 1. Proposed reseach model

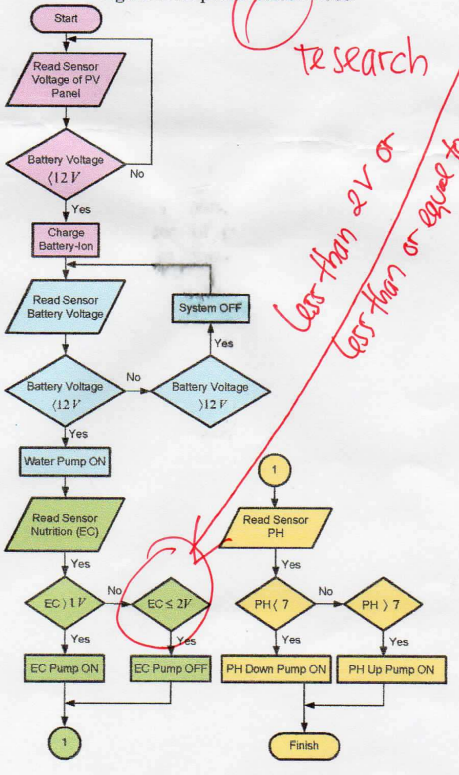

Figure 2. Research flowcart

Figure 1 shows the proposed research model. The 100 Wp standalone photovoltaic (PV) module charges the battery (Lithium-Ion). After the battery is fully charged, the EC sensor and PH sensor will work. The Arduino Uno circuit with a 20 × 4 LCD display will then order four relays i.e. water flow pump, nutrient (EC) pump, pH-up pump, and pH-down pump to work to control the hydroponic system in a greenhouse based on the coding which has been written previously on Arduino-Uno. Figure 2 shows the research flowchart. The research starts with the sensor reading the PV module output voltage. If the battery voltage is less than 12 V, the PV power will charge previously the battery. Then, the battery voltage sensor will work logically if the battery voltage is less than 12 V, then the water flow pump will work. Whereas if the battery voltage exceeds 12 V, the system will shut down. After the water pump starts, the nutrition sensor (EC) will work logically if the EC voltage is greater than 1 then the EC pump will turn on and if the EC voltage is less than 2 then the EC pump will shut down. Furthermore, the pH sensor works to monitor the pH level of the water. If the pH level is below 7 then the PH pump down will work (On), conversely, if the pH level is above 7 then the pH up pump will work (On).

B. Modelling Photovoltaic

The equivalent circuit of PV is shown in Figure 3. It consists of several PV cells which have external connections in series, parallel, or series-parallel [5].

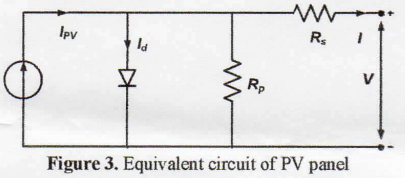

Figure 3. Equivalent circuit of PV panel

The V-I characteristic is shown in Eq. (1):

$$I = I_{PV} - I_o\left[exp\left(\frac{V+R_S I}{a\,V_t}\right) - 1\right] - \frac{V+R_S I}{R_P} \quad (1)$$

Where I_{PV} is PV current, I_o is saturated re-serve current, 'a' is the ideal diode constant, $Vt = N_S K T q^{-1}$ is the thermal voltage, N_S is a number of series cells, q is the electron charge, K is Boltzmann constant, T is temperature pn junction, R_S and R_P are series and parallel resistance of solar panels. I_{PV} has a linear relationship with light intensity and also varies with temperature variations. I_o is a dependent value on the temperature variation. Eq. (2) and Eq. (3) are the calculation of I_{PV} and I_o values:

$$I_{PV} = \left(I_{PV,n} + K_I \Delta T\right)\frac{G}{G_n} \quad (2)$$

$$I_o = \frac{I_{SC,n} + K_I \Delta T}{exp\,(V_{OC,n} + K_V \Delta T)/aV_t - 1} \quad (3)$$

Where $I_{PV,n}$, $I_{SC,n}$, and $V_{OC,n}$ are the photovoltaic current, short circuit current, and open-circuit voltage under standard conditions ($T_n = 25^0 C$ and $G_n = 1000\,W/m^2$), respectively. The K_I value is the coefficient of short circuit current to temperature, $\Delta T = T - T_n$ is temperature deviation from standard

temperature, G is the light intensity and K_V is coefficient of open-circuit voltage ratio to temperature. Open circuit voltage, short circuit current, and voltage-current related to maximum power are three important values of I-V characteristics of PV panel. These points are changed by variation in atmospheric conditions. By using Eq. (4) and Eq. (5) derived from the PV model equation, short-circuit current and open-circuit voltage can be calculated under different atmospheric conditions.

$$I_{SC} = (I_{SC} + K_I \Delta T)\frac{G}{G_n} \quad (4)$$

$$V_{OC} = (V_{OC} + K_V \Delta T) \quad (5)$$

C. *Green House*

The greenhouse is a frame or corrugated building covered with a clear or translucent material that can transmit light optimally for production and protect plants from climatic conditions that are detrimental to plant growth. The cultivating of plants in a greenhouse has the advantage of a more controlled microenvironment and uniformity of production for each plant. The functions of a greenhouse include managing plant growth schedules, increasing production yields, minimizing pesticides, increasing production quality, assets, and performance, as well as a means of agro-tourism [6].

D. *Arduino Uno*

Arduino-Uno is an electronic board containing an ATMega328 microcontroller, which is a chip that functionally acts like a computer. This device is used to realize electronic circuits from simple to complex. LED control to robot control can be used. implemented using this relatively small board. In the health sector with the addition of certain components, this tool can be used to monitor the condition of patients in the hospital and control equipment at home [7]. Figure 4 shows the Arduino Uno model.

Figure 4. Arduino Uno model

E. *Relay Circuit*

The relay circuit is a link between the Arduino Uno circuit with the water flow pump, nutrient pump (EC), pH-up pump, and pH-down pump to work on controlling the greenhouse hydroponic system based on the coding previously programmed on Arduino-Nano. Figure 5 shows a relay circuit on the greenhouse hydroponic system.

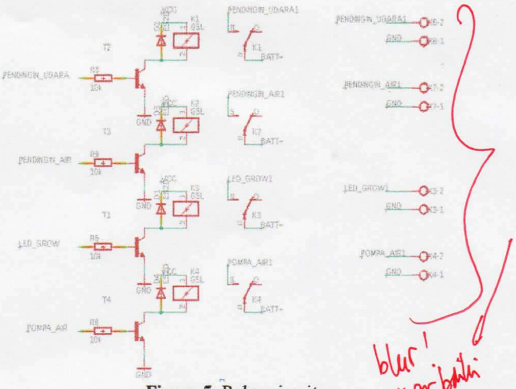

Figure 5. Relay circuit

F. *Sensor Electrical Conductivity*

The Electrical Conductivity (EC) sensor is used to measure the concentration of a solution for example hydroponic nutrient solution which is expressed in units of miliSiemens per centimeter (mS/cm). The EC-meter is an alternative measurement device to the Total Dissolved Solids (TDS)-meter to measure the concentration of a hydroponic nutrient solution expressed in units of parts per million (ppm) [8]. The EC value affects the rate of nutrition absorption by plants, the greater the EC value, the faster the absorption of nutrition by plants and vice versa if the EC value is smaller, the absorption of nutrition will be slow [9]. The series of EC sensors installed in the greenhouse hydroponic system is connected to the Arduino-Uno, using the IDE software and libraries in the Arduino Uno. Figure 6 shows the EC sensor circuit.

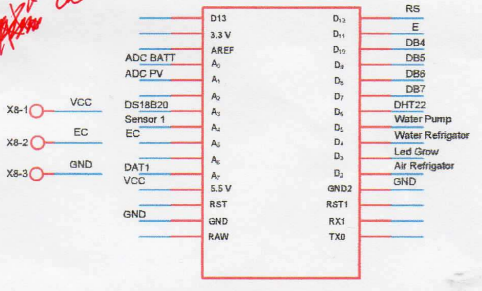

Figure 6. EC sensor circuit

G. *Sensor pH*

The pH sensor is an instrument for measuring the concentration of hydrogen in a solution. The pH sensors for water and for soil need to be calibrated periodically so that the accuracy of the measurement is guaranteed. The series of pH sensors installed in the greenhouse hydroponic system is connected to the Arduino-Uno, using the IDE software and libraries in the Arduino Uno. The pH sensor circuit is shown in Figure 7.

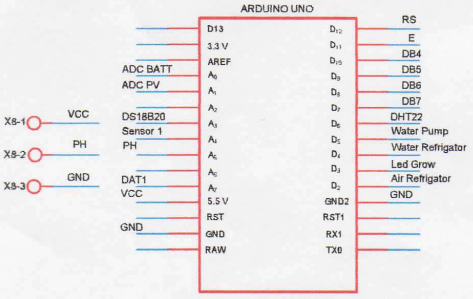

Figure 7. The pH sensor circuit

H. Liquid Crystal Display

Liquid Crystal Display (LCD) is a type of display media that uses liquid crystals as the main display. LCD has been used in various fields, for example in electronic devices, such as televisions, calculators, or computer screens. The LCD circuit that is installed with a greenhouse hydroponic is connected to the Arduino-Uno, using the IDE software and libraries in the Arduino Uno. Figure 8 shows the LCD circuit.

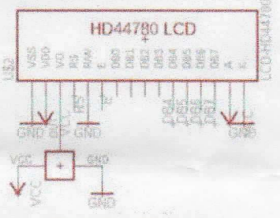

Figure 8. LCD circuit

III. RESULTS AND DISCUSSION

Figure 9 shows the implementation of a monitoring system for pH and plant nutrition in a greenhouse hydroponic system using Arduino Uno. Figure 7.a shows (1) Arduino-Uno Controller, (2) Solenoid Valve, (3) Hydroponic Plant, (4) Nutrition EC, (5) pH-up, and (6) pH-down. Figure 7.b. shows nutrient water and sensors. Figure 7.c shows the PV module connected to a battery (Lithium-Ion). The working mechanism of this prototype is started by the sensors read the output voltage of the PV module. If the battery voltage is less than 12 V, the PV output power will charge the battery. In this condition, the battery voltage sensor will work and the water pump will also work. After the water pump starts then the EC sensor also works, with logic if the EC level is greater than 1 then the EC pump will turn on and if the EC level is less than 2 then the EC pump will shut down. Furthermore, the pH sensor works to monitor the PH level of the water. If the PH level is below 7 then the PH-down pump will work (On), otherwise if the pH level is above 7 then the pH-up pump will work (On). To obtain better monitoring and control system performance, a number of validation measurements are carried out i.e. PV voltage, battery voltage, EC sensor, and pH sensor.

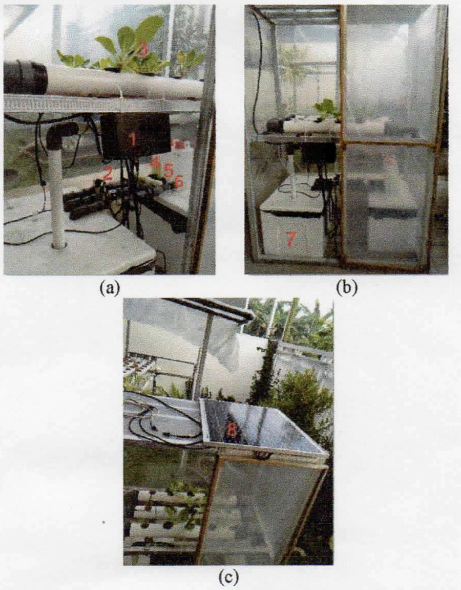

Figure 9. Implementation of a monitoring system for pH and plant nutrition in a greenhouse hydroponic system

Table 1. Measurement of PV voltage

No.	Volt Meter (V)	Sensor Tegangan PV (V)	Error (%)
1	5.00	5.07	1.400
2	7.00	7.10	1.429
3	9.00	9.09	1.000
4	12.00	12.08	0.667

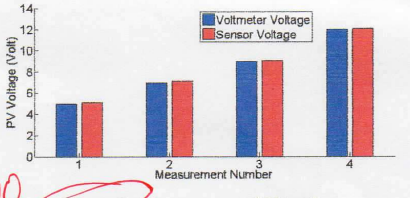

Figure 9. Measurement of PV voltage

Table 1 and Figure 9 show the PV voltage measurement using a voltmeter and a PV voltage sensor. The first measurement with a voltmeter produces a PV voltage of 5 V, while the measurement uses a sensor as 5.07 V. The fourth measurement with a voltmeter produces a PV voltage of 12 V, while the measurement uses a sensor as 12.08 V. The four measurement results show that the PV voltage sensor produces a measurement accuracy close to the same compared to measurements using a voltmeter with a maximum error of 1.429% or already below 5%.

Table 2 and Figure 10 show the battery voltage measurement using a voltmeter and a battery voltage sensor. The first measurement with a voltmeter produces a PV voltage of 5 V, while the measurement using a sensor resulting of 5.10 V. The fourth measurement with a voltmeter produces a PV voltage of 12 V, while the measurement using a sensor resulting of 12.07 V.

Table 2. Measurement of battery voltage

No.	Volt Meter (V)	Sensor Tegangan Baterai (V)	Error (%)
1	5.00	5.10	2.000
2	7.00	7.06	0.857
3	9.00	9.09	1.000
4	12.00	12.07	0.583

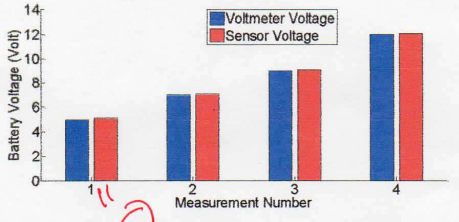

Figure 10. Measurement of battery voltage

The four measurements show that the battery voltage sensor produces a measurement accuracy close to the same compared to measurements using a battery with a maximum error of 2% or already below 5%. PH sensor measurements are carried out to ensure the sensor can run properly because it can affect pH measurements when monitoring equipment is applied to hydroponic plants in greenhouses. Figure 11 shows pH measurements using a digital pH-meter. Figure 12 shows pH measurements using a pH sensor. Table 3 shows the measurements of water pH using a digital pH meter and pH sensor. Figure 13 shows the comparison of the pH of the water using a digital-meter and sensor.

Figure 11. pH measurement using digital-meter

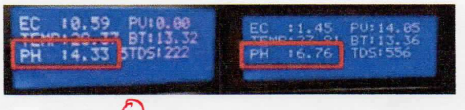

Figure 12. pH measurement using sensor

Table 3 Measurements of water pH using a digital pH meter and pH sensor

No.	PH air	Digital PH meter	Sensor PH	Error (%)
1	4.00	4.0	4.33	8.250
2	6.86	6.8	6.76	1.458

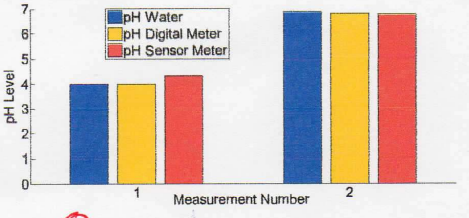

Figure 13. Comparison of the pH water using a digital-meter and sensor

Table 3 and Figure 13 show that on measurement 1 the pH value of water is 4, read by digital pH meter and pH sensor of 4.0 and 4.33, respectively. Meanwhile, measurement 2 shows that the pH value of the water is 6.86, which is read by a digital pH meter and a pH sensor of 6.8 and 6.76, respectively. Table 3 shows that measurements using a digital pH meter and a pH sensor are able to give close to the same results. The measurement results of pH sensors with water pH below 6 are still inaccurate because they produce an error of 8.250%. However, the measurement of pH sensors with water pH values between 6-7 is relatively accurate because it produces an error of 1.458% or is already below 5%. EC sensor measurements are carried out to ensure the nutrient sensor is functioning properly, because this indicator will affect the EC measurement of the water when the monitoring system is running. Table 4 shows the measurement of nutrition levels using the TDS sensor and the EC sensor.

Table 4. Nutrition measurement using TDS and EC sensors

No.	Digital TDS (ppm)	Sensor TDS (ppm)	Sensor EC (mS/cm)
1	450	458	1.23
2	540	542	1.45
3	760	765	2.05
4	880	882	2.30

The performance measurement of the pH monitoring system is carried out to ensure that the pH of the water can be controlled to a degree of acidity between 6-7. This range of values is needed to keep hydroponic plant growth relatively stable. Measurements are made on a hydroponic plant monitoring system, using a relay that functions to run the pH pump motor. The function of pH-Up and pH-Down is to keep the pH of hydroponic plant water at the level of 6-7. Table 5 shows the performance measurements of the pH sensor. Figure 14 shows the measurement of pH-Up performance at 08.00 and 14.00 hours.

Table 5. Performance measurement using pH sensor

Hours	Sensor pH	pH-Up	pH Down
08.00	4.33	On	Off
10.00	6.45	Off	Off
12.00	6.76	Off	Off
14.00	7.32	Off	On
16.00	6.47	Off	Off

Figure 14. Performance measurement of pH-Up at 08.00 and 14.00 hours

Table 5 and Figure 14 show that at 08.00 the pH level is below 6 so that the pH-Up sensor is on. In this condition, the solenoid valve will open to drain pH-Up water so that the pH value rises to above 6. On the other hand, at 10.00, 12.00, 14.00, and 16.00 the pH level is above 6 so that the pH-Up sensor is in the Off status. Table 5 and Figure 6 also show that at 14.00 hours the pH level is above 7 so that the pH-down sensor is On. In this condition, the solenoid valve will open to drain pH-down water to lower the pH value to below 7. On the other hand, at 08.00, 10.00, 12.00, and 16.00 hours the pH level are already below 7 so that the pH-down sensor is automatically in the Off status.

The performance measurement of EC is carried out to ensure that the water nutrition concentration can be controlled within a value range of 1-2 mS/cm. The EC control is needed to keep hydroponic plant growth relatively stable. The measurements are made on the hydroponic plant monitoring system, using a relay that functions to run the EC pump motor. Table 6 shows the performance measurements using an EC sensor. Figure 15 shows the measurement of EC at 08.00 and 16.00 hours.

Table 6. Performance measurements using EC sensor

Jam	Sensor EC	EC-Up
08.00	0.59	On
10.00	1.45	Off
12.00	1.28	Off
14.00	1.32	Off
16.00	1.30	Off

Gambar 16. Performance measurement of EC sensor at 08.00 and 16.00 hours

Table 6 and Figure 16 show that at 08.00 hours the level of EC nutrition is still below 1 so that the EC-Up sensor is On. In this condition, the solenoid valve will open to drain EC water and raise the pH level to above 1. On the other hand, at 10.00, 12.00, 14,000, and 16.00 the EC nutrient level is already above 1 so that the EC-Up sensor is automatically in the Off status.

IV. Conclusion

The prototype model to monitor and control the pH levels and EC nutrition plant supplied by a standalone PV module-connected battery on greenhouse hydroponic systems has been implemented. The two sensors are connected to the Arduino Uno and relay control to drive four pumps, i.e. the water flow pump, EC pump, pH up pump, and pH down pump. The prototype model is able to monitor and control the pH of hydroponic plant water at the level between 6-7 using pH-up and pH-down sensor. This model is also able to monitor and control nutrition plant water over 1 mS/cm using EC sensor. The implementation of the EC sensor is only able to control the EC value if the value is less than 1 mS/cm. On the other hand, optimal plant growth in a hydroponic greenhouse system requires controlled EC values between 1-2 mS/cm. The use of an EC-down sensor to control the EC value so as not to exceed the 2 mS/cm value is proposed as future work to overcome this problem.

Acknowledgement

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Lampiran 2.4

Hasil revisi penulis terhadap review pertama

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Monitoring and Controlling of pH Levels and Plant Nutrition Supplied by Standalone Photovoltaic in a Greenhouse Hydroponic System using Arduino Uno

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***Abstract* – This paper aims to implement the prototype model to monitor and control the pH levels and nutrition plant (electrical conductivity-EC) supplied by a standalone photovoltaic (PV) module-connected battery (Lithium-Ion) on the greenhouse hydroponic systems. The two sensors are connected to the Arduino Uno circuit as a relay control to drive four pumps, i.e. the water flow pump, EC pump, pH up pump, and pH down pump. The greenhouse function to control pests and the impact of environmental non-uniformity caused by variation of wind speed, temperature, or sunlight so that hydroponic plants can grow in an appropriate environment. The Arduino Uno circuit with a 20 × 4 liquid crystal display (LCD) order four relays to monitor and control the four pumps of greenhouse hydroponic system based on the coding which has been programmed previously. The prototype model is able to monitor and control the pH of hydroponic plant water at the level between 6-7 using a pH-up and pH-down sensor. This model is also able to monitor and control nutrition plant water over 1 mS/cm using an EC sensor. The proposed prototype is able to monitor and control pH levels between 6-7 and plant nutrients (EC) above 1 mS/cm to maintain plant growth in the hydroponic greenhouse system normal.**

Keywords: Standalone PV, pH, EC, Greenhouse, Hydroponic, Arduino Uno

I. INTRODUCTION

Recently, hydroponics has become a new method of cultivating plants, especially various types of vegetables or fruit, because they do not require large areas of land and can be done in the yard of the house. The hydroponic method uses a solution of mineral nutrients and water without using soil media for the process of growing and maintaining plants. Hydroponic cultivation in greenhouses is now an option to overcome the constraints of cultivating plants in open areas i.e. attack by pests, wind, temperature, and sunlight which sometimes also interfere with the growth and development of vegetable or fruit plants.

The PV module is a source of electrical power to operate the pH control system and the water level of hydroponic plant nutrients until the harvest period has been implemented on [1]. The proposed prototype was able to control the water pH level of 6-7 and the nutrition solution height of 18-20 cm. This model works when the pH sensor detects below 6 then the solenoid valve at pH-up automatically opens and flows into the nutrition solution. Thus, when the sensor detects a pH of more than 7, the solenoid valve will open and the pH-down solution will flow into the nutrition solution. The solenoid valve will close again when the sensor detects the pH in the range of 6-7. The water level control works when the ultrasonic sensor detects a value of 18 cm, the solenoid valve will open and the nutrition water flows into the nutrition bath, otherwise, the solenoid valve closes again when the sensor detects a value of 20 cm. However, this prototype did not use an EC sensor to detect the level of the nutrition solution in the water. The pH control and nutrient levels are regulated by a solenoid valve, actuated by a water pump, and the power is supplied by the PV module for 24 hours with varying tilt angles.

The EC wireless sensor supplied by Indonesia Electric Company (PLN) grid to monitor and control the concentration of the nutrient solution for hydroponic plant cultivation using two Nutrient Film Technique (NFT) tables based has been proposed on [2]. Each table was installed with monitoring and controlling of nutrition solution concentration devices which transmit the data to server through wireless sensor network. The results showed that the EC-meter sensor was able to read the density of the nutrient solution with a relative error percentage of 3.92%. Node 2 was able to produce a faster threshold data transmission than node 1 with a delay for node 2 of 34.68 seconds and a delay for node 1 of 40.01 seconds. Node 1 was able to result in a better control accuracy of nutrient solution concentration at 96.12% compared to node 2 at 92.79%. The weakness of this model was the performance of monitoring and control depending on temperature and the distance between the node and the coordinator. The higher the system temperature, so its performance also decreases. The farther the distance between the node and the coordinator, the loss of data transmission also will be greater.

The nutritional control, water temperature, water volume, environmental temperature, pH, and humidity on the hydroponic system using the website has been implemented in [3]. The control of this prototype used the NodeMCU esp8266 v3 microcontroller. Data communication between hardware and software used wireless media. Temperature reading system water using the DS18B20 sensor, the water level using the HC-SR04 ultrasonic sensor, and the nutrition level measured by the nutrition solution sensor. This device was designed to be

able to monitor and control the hydroponic system at nutrient temperatures at 23°C-27°C, water height limits 5-10 cm and nutrient levels at the 600-800 ppm limit. The weakness of this research was that it still operates using the website browser menu so that it requires internet access to monitor and control all parameters through this prototype model. The design of PV modules as a power source for DC pump and compared by AC pump to control water flow that supplies nutrients to NFT-type hydroponic plants has been proposed on [4]. This model showed that the use of solar panels and DC pumps to flow water to hydroponic plants is relatively more economical than an AC pump. However, the DC pump was not able to operate continuously, and to overcome this problem then the researchers proposed an AC pump using a DC-AC inverter to drain water in the hydroponic system.

Control of pH and nutrition water levels in the hydroponic system of chili plants using Arduino Uno with microcontroller ATmega16 U2 has been observed in [5]. This prototype was capable of controlling a pH level between 6-6.5 and a nutrition water level between 6-8 cm. The prototype of measuring and controlling water volume and water pH levels in hydroponic system using ultrasonic sensor and pH sensor with Arduino Uno have been proposed in [6]. The proposed system was capable of controlling water level between 10-14 cm and water pH between 5.5-7.5. The prototype of the EC control and water volume on hydroponic system using fuzzy logic has been observed in [7]. Fuzzy logic control using the EC sensor was able to control EC between 110-2000 µS/cm and generate good performance with an average error of 1.91%. This model was also able to control the volume of water between 10-100 mL with an average error of 1.87%. Nevertheless, the drawback of prototype model in [1-3] was completely dependent on grid electricity so that if there is a supply disruption at the source side, the control and monitoring of hydroponic system will not be able to function normally.

This research will implement the prototype model to monitor and control the pH levels and nutrition plant supplied by a 100 watt-peak (Wp) standalone PV panel-connected battery on greenhouse hydroponic systems. The two sensors are connected to the Arduino Uno circuit as a relay control to drive four pumps, i.e. the water flow pump, EC pump, pH up pump, and pH down pump. The greenhouse function to control pests and environmental temperatures so that hydroponic plants can grow in an appropriate environment. The paper is arranged as follows. Chapter II presents the proposed research model, flow chart, PV module concept, greenhouse, Arduino Uno, relay circuit, pH sensor, EC sensor, liquid crystal display (LCD). Chapter III presents the results and discussion i.e. the design of monitoring and control systems for pH and EC levels, measurement and validating the PV and battery module voltages, measurement and validating pH sensor, measurement and validating EC sensor as well as analyzing the performance measurement result of pH sensor and EC sensor in greenhouse hydroponic plant systems. Finally, the paper is concluded in Chapter IV.

II. METHODOLOGY

A. *Research Method*

The monitoring and control system for pH and EC nutrition in the hydroponic greenhouse prototype consists of a combination of hardware and software. The hardware design consists of a PV module, battery (Lithium-Ion), pH sensor, and EC nutrition sensor combined with Arduino Uno software connected to four relays. These relays function to control the water flow pump, nutrient pump (EC), pH-up pump, and pH-down pump. The block diagram of the proposed model can be seen in Figure 1.

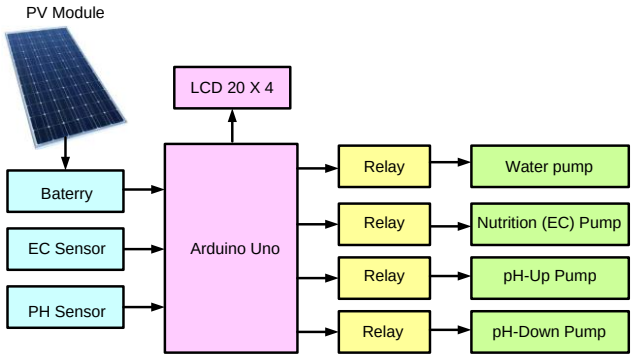


Figure 1. Proposed research model

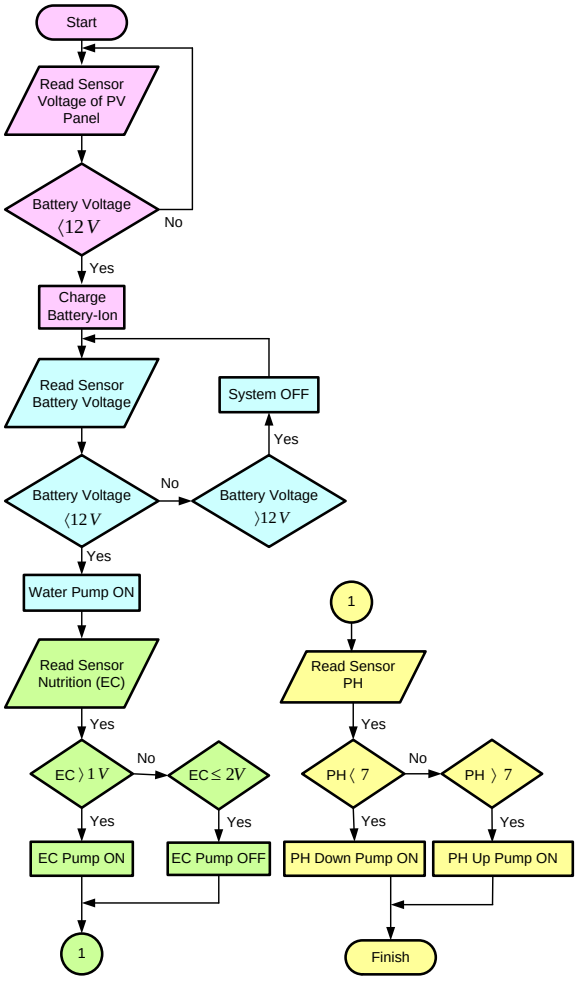


Figure 2. Research flowcart

Figure 1 shows the proposed research diagram of the monitoring system for pH and plant nutrition in a

greenhouse hydroponic system using Arduino Uno. The 100 Wp standalone photovoltaic (PV) module charges the battery (Lithium-Ion). After the battery is fully charged, the EC sensor and PH sensor will work. The Arduino Uno circuit with a 20 × 4 LCD display will then order four relays i.e. water flow pump, nutrient (EC) pump, pH-up pump, and pH-down pump to work to control the hydroponic system in a greenhouse based on the coding which has been written previously on Arduino-Uno. Figure 2 shows the research flowchart. The research starts with the sensor reading the PV module output voltage. If the battery voltage is less than 12 V, the PV power will charge previously the battery. Then, the battery voltage sensor will work logically if the battery voltage is less than 12 V, then the water flow pump will work. Whereas if the battery voltage exceeds 12 V, the system will shut down. After the water pump starts, the nutrition sensor (EC) will work logically if the EC voltage is greater than 1 then the EC pump will turn on and if the EC voltage is less than 2 then the EC pump will shut down. Furthermore, the pH sensor works to monitor the pH level of the water. If the pH level is below 7 then the PH pump down will work (On), conversely, if the pH level is above 7 then the pH up pump will work (On).

B. *Modelling Photovoltaic*

The equivalent circuit of PV is shown in Figure 3. It consists of several PV cells which have external connections in series, parallel, or series-parallel [5].

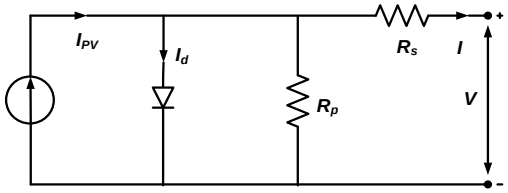


Figure 3. Equivalent circuit of PV panel

The V-I characteristic is shown in Eq. (1):

$$I = I_{PV} - I_o \left[exp\left(\frac{V+R_S I}{a\, V_t}\right) - 1 \right] - \frac{V+R_S I}{R_P} \qquad (1)$$

Where I_{PV} is PV current, I_o is saturated re-serve current, 'a' is the ideal diode constant, $Vt = N_S K T q^{-1}$ is the thermal voltage, N_S is a number of series cells, q is the electron charge, K is Boltzmann constant, T is temperature pn junction, R_S and R_P are series and parallel resistance of solar panels. I_{PV} has a linear relationship with light intensity and also varies with temperature variations. I_o is a dependent value on the temperature variation. Eq. (2) and Eq. (3) are the calculation of I_{PV} and I_o values:

$$I_{PV} = \left(I_{PV,n} + K_I \Delta T\right) \frac{G}{G_n} \qquad (2)$$

$$I_o = \frac{I_{SC,n} + K_I \Delta T}{exp\,(V_{OC,n} + K_V \Delta T)/aV_t - 1} \qquad (3)$$

Where, $I_{PV,n}$, $I_{SC,n}$, and $V_{OC,n}$ are the photovoltaic current, short circuit current, and open-circuit voltage under standard conditions ($T_n = 25^0 C$ and $G_n = 1000\, W/m^2$), respectively. The K_I value is the coefficient of short circuit current to temperature, $\Delta T = T - T_n$ is temperature deviation from standard temperature, G is the light intensity and K_V is coefficient of open-circuit voltage ratio to temperature. Open circuit voltage, short circuit current, and voltage-current related to maximum power are three important values of I-V characteristics of PV panel. These points are changed by variation in atmospheric conditions. By using Eq. (4) and Eq. (5) derived from the PV model equation, short-circuit current and open-circuit voltage can be calculated under different atmospheric conditions.

$$I_{SC} = (I_{SC} + K_I \Delta T) \frac{G}{G_n} \qquad (4)$$

$$V_{OC} = (V_{OC} + K_V \Delta T) \qquad (5)$$

C. *Green House*

The greenhouse is a frame or corrugated building covered with a clear or translucent material that can transmit light optimally for production and protect plants from climatic conditions that are detrimental to plant growth. The cultivating of plants in a greenhouse has the advantage of a more controlled microenvironment and uniformity of production for each plant. The functions of a greenhouse include managing plant growth schedules, increasing production yields, minimizing pesticides, increasing production quality, assets, and performance, as well as a means of agro-tourism [6].

D. *Arduino Uno*

Arduino-Uno is an electronic board containing an ATMega328 microcontroller, which is a chip that functionally acts like a computer. This device is used to realize electronic circuits from simple to complex. LED control to robot control can be implemented using this relatively small board. In the health sector with the addition of certain components, this tool can be used to monitor the condition of patients in the hospital and control equipment at home [7]. Figure 4 shows the Arduino Uno model.

Figure 4. Arduino Uno model

E. *Relay Circuit*

The relay circuit is a link between the Arduino Uno circuit with the water flow pump, nutrient pump (EC), pH-up pump, and pH-down pump to work on controlling the greenhouse hydroponic system based on the coding previously programmed on Arduino-Nano. Figure 5 shows a relay circuit on the greenhouse hydroponic system.

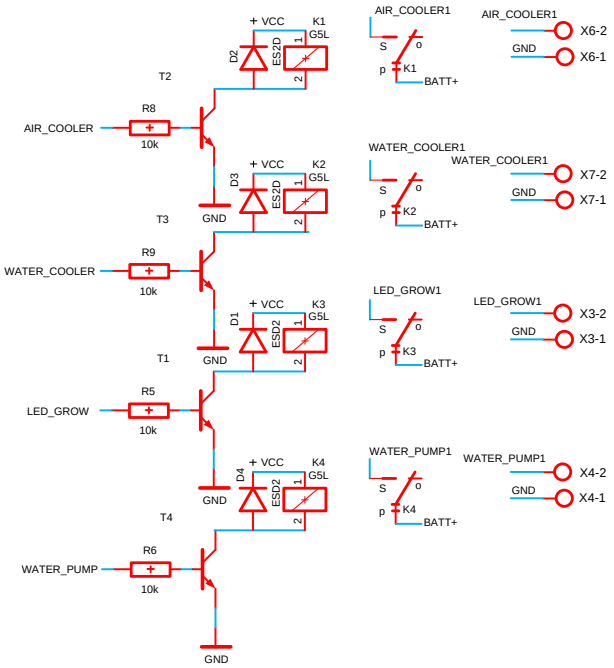


Figure 5. Relay circuit

F. *Sensor Electrical Conductivity*

The Electrical Conductivity (EC) sensor is used to measure the concentration of a solution for example hydroponic nutrient solution which is expressed in units of miliSiemens per centimeter (mS/cm). The EC-meter is an alternative measurement device to the Total Dissolved Solids (TDS)-meter to measure the concentration of a hydroponic nutrient solution expressed in units of parts per million (ppm) [8]. The EC value affects the rate of nutrition absorption by plants, the greater the EC value, the faster the absorption of nutrition by plants and vice versa if the EC value is smaller, the absorption of nutrition will be slow [9]. The series of EC sensors installed in the greenhouse hydroponic system is connected to the Arduino-Uno, using the IDE software and libraries in the Arduino Uno. Figure 6 shows the EC sensor circuit.

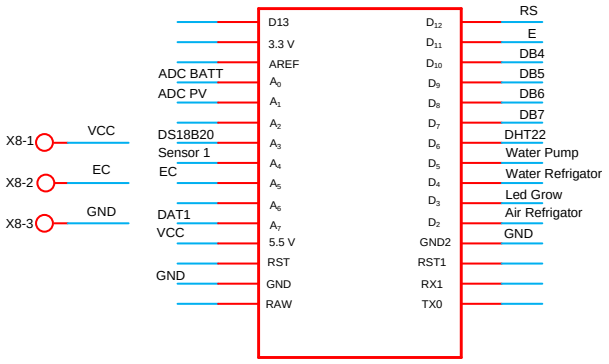


Figure 6. EC sensor circuit

G. *Sensor pH*

The pH sensor is an instrument for measuring the concentration of hydrogen in a solution. The pH sensors for water and for soil need to be calibrated periodically so that the accuracy of the measurement is guaranteed. The series of pH sensors installed in the greenhouse hydroponic system is connected to the Arduino-Uno, using the IDE software and libraries in the Arduino Uno. The pH sensor circuit is shown in Figure 7.

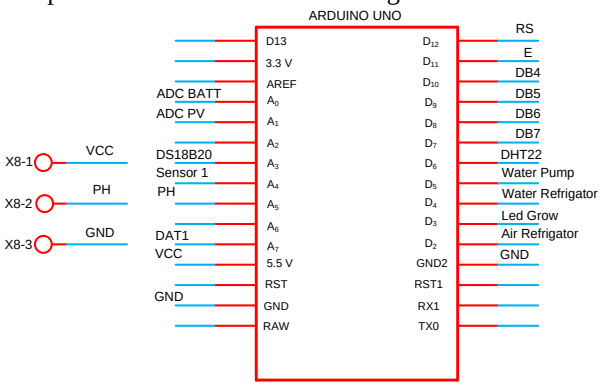


Figure 7. The pH sensor circuit

H. *Liquid Crystal Display*

Liquid Crystal Display (LCD) is a type of display media that uses liquid crystals as the main display. LCD has been used in various fields, for example in electronic devices, such as televisions, calculators, or computer screens. The LCD circuit that is installed with a greenhouse hydroponic is connected to the Arduino-Uno, using the IDE software and libraries in the Arduino Uno. Figure 8 shows the LCD circuit.

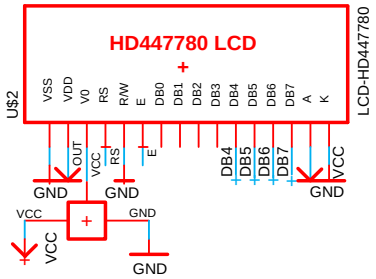
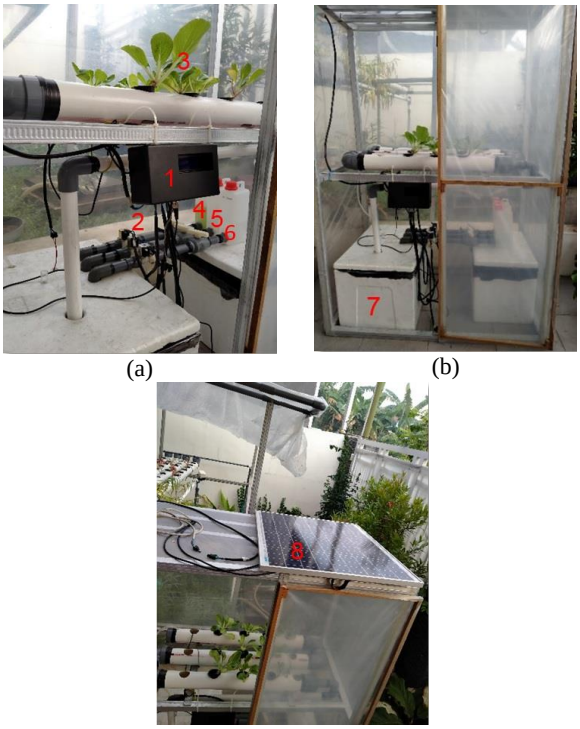


Figure 8. LCD circuit

III. Results and Discussion

Figure 9 shows the implementation of a monitoring system for pH and plant nutrition in a greenhouse hydroponic system using Arduino Uno. Figure 9.a shows (1) Arduino-Uno Controller, (2) Solenoid Valve, (3) Hydroponic Plant, (4) Nutrition EC, (5) pH-up, and (6) pH-down. Figure 9.b. shows nutrient water and sensors. Figure 9.c shows the PV module connected to a battery (Lithium-Ion). The working mechanism of this prototype is started by the sensors read the output voltage of the PV module. If the battery voltage is less than 12 V, the PV output power will charge the battery. In this condition, the battery voltage sensor will work and the water pump will also work. After the water pump starts then the EC sensor also works, with logic if the EC level is greater than 1 then the EC pump will turn on and if the EC level is less than 2 then the EC pump will shut down. Furthermore, the pH sensor works to monitor the PH level of the water. If the PH level is below 7 then the PH-down pump will work (On), otherwise if the pH level is above 7 then the pH-up pump will work (On). To obtain better monitoring and control system performance,

a number of validation measurements are carried out i.e. PV voltage, battery voltage, EC sensor, and pH sensor.



(a) (b)

(c)

Figure 9. Implementation of a monitoring system for pH and plant nutrition in a greenhouse hydroponic system

Table 1. Measurement of PV voltage

No.	Volt Meter (V)	PV Voltage Sensor (V)	Error (%)
1	5.00	5.07	1.400
2	7.00	7.10	1.429
3	9.00	9.09	1.000
4	12.00	12.08	0.667

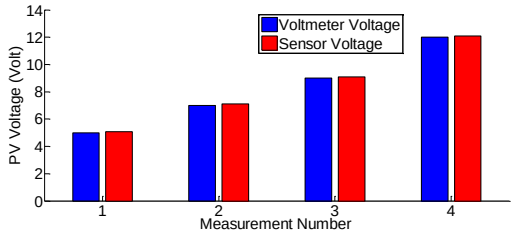


Figure 10. Measurement of PV voltage

Table 1 and Figure 10 show the PV voltage measurement using a voltmeter and a PV voltage sensor. The first measurement with a voltmeter produces a PV voltage of 5 V, while the measurement uses a sensor as 5.07 V. The fourth measurement with a voltmeter produces a PV voltage of 12 V, while the measurement uses a sensor as 12.08 V. The four measurement results show that the PV voltage sensor produces a measurement accuracy close to the same compared to measurements using a voltmeter with a maximum error of 1.429% or already below 5%.

Table 2 and Figure 11 show the battery voltage measurement using a voltmeter and a battery voltage sensor. The first measurement with a voltmeter produces a PV voltage of 5 V, while the measurement using a sensor resulting of 5.10 V. The fourth measurement with a voltmeter produces a PV voltage of 12 V, while the measurement using a sensor resulting of 12.07 V.

Table 2. Measurement of battery voltage

No.	Volt Meter (V)	Battery Voltage Sensor (V)	Error (%)
1	5.00	5.10	2.000
2	7.00	7.06	0.857
3	9.00	9.09	1.000
4	12.00	12.07	0.583

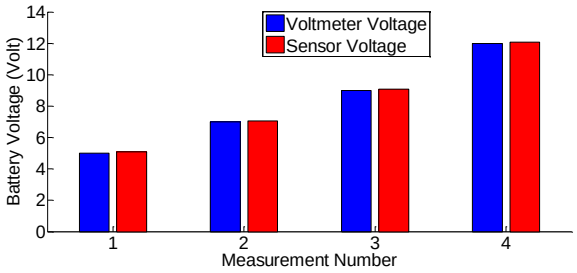


Figure 11. Measurement of battery voltage

The four measurements on Table 2 and Figure 11 show that the battery voltage sensor produces a measurement accuracy close to the same compared to measurements using a battery with a maximum error of 2% or already below 5%. PH sensor measurements are carried out to ensure the sensor can run properly because it can affect pH measurements when monitoring equipment is applied to hydroponic plants in greenhouse. Figure 12 shows pH measurements using a digital pH-meter. Figure 13 shows pH measurements using a pH sensor. Table 3 shows the measurements of water pH using a digital pH meter and pH sensor. Figure 13 shows the comparison of the pH of the water using a digital-meter and sensor.

Figure 12. pH measurement using digital-meter

Figure 13. pH measurement using sensor

Table 3 Measurements of water pH using a digital pH meter and pH sensor

No.	PH Water	Digital PH meter	Error (%)	Sensor PH	Error (%)
1	4.00	4.0	0	4.33	8.250
2	6.86	6.8	0.875	6.76	1.458

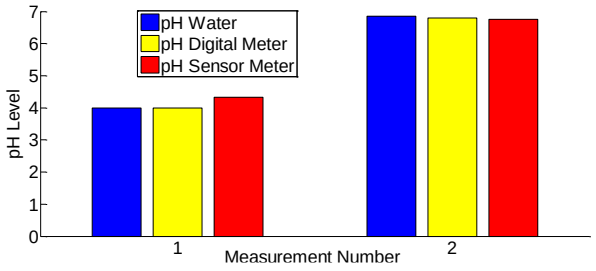


Figure 14. Comparison of the pH water using a digital-meter and sensor

Table 3 and Figure 14 show that on first measurement the pH value of water is 4, read by digital pH meter and pH sensor of 4.0 and 4.33, respectively. Otherwise, on the second measurement shows that the pH value of the water is 6.86, which is read by a digital pH meter and a pH sensor of 6.8 and 6.76, respectively. Table 3 shows that measurements using a digital pH meter and a pH sensor are able to give close to the same results. The measurement results of digital pH meter with water pH below 6 is accurate because they produce an error of 0%. Then, the measurement of pH digital meter with water pH values between 6-7 is relatively accurate because it produces an error of 0.875% or is already below 5%.

Table 3 and Figure 14 also show that on the first measurement results of pH sensors with water pH below 6 are still inaccurate because they produce an error of 8.250%. However, on the second measurement of pH sensors with water pH values between 6-7 is relatively accurate because it produces an error of 1.458% or is already below 5%. EC sensor measurements are carried out to ensure the nutrition sensor is functioning properly, because this indicator will affect the EC measurement of the water when the monitoring system is running. Table 4 shows the measurement of nutrition levels using the TDS sensor and the EC sensor.

Table 4. Nutrition measurement using TDS and EC sensors

No.	Digital TDS (ppm)	Sensor TDS (ppm)	Sensor EC (mS/cm)
1	450	458	1.23
2	540	542	1.45
3	760	765	2.05
4	880	882	2.30

The performance measurement of the pH monitoring system is carried out to ensure that the pH of the water can be controlled to a degree of acidity between 6-7. This range of values is needed to keep hydroponic plant growth relatively stable. The measurements are made on a hydroponic plant monitoring system, using a relay that functions to run the pH pump motor. The function of pH-Up and pH-Down is to keep the pH of hydroponic plant water at the level of 6-7. Table 5 shows the performance measurements of the pH sensor. Figure 15 shows the measurement of pH-Up performance at 08.00 and 14.00 hours.

Table 5. Performance measurement using pH sensor

Hours	Sensor pH	pH-Up	pH-Down
08.00	4.33	On	Off
10.00	6.45	Off	Off
12.00	6.76	Off	Off
14.00	7.32	Off	On
16.00	6.47	Off	Off

Figure 15. Performance measurement of pH-Up at 08.00 and 14.00 hours

Table 5 and Figure 15 show that at 08.00 the pH level is below 6 so that the pH-Up sensor is on. In this condition, the solenoid valve will open to drain pH-Up water so that the pH value rises to above 6. On the other hand, at 10.00, 12.00, 14.00, and 16.00 the pH level is above 6 so that the pH-Up sensor is in the Off status. Table 5 and Figure 15 also show that at 14.00 hours the pH level is above 7 so that the pH-down sensor is On. In this condition, the solenoid valve will open to drain pH-down water to lower the pH value to below 7. On the other hand, at 08.00, 10.00, 12.00, and 16.00 hours the pH level are already below 7 so that the pH-down sensor is automatically in the Off status.

The performance measurement of EC is carried out to ensure that the water nutrition concentration can be controlled within a value range of 1-2 mS/cm. The EC control is needed to keep hydroponic plant growth relatively stable. The measurements are made on the hydroponic plant monitoring system, using a relay that functions to run the EC pump motor. Table 6 shows the performance measurements using an EC sensor. Figure 15 shows the measurement of EC at 08.00 and 16.00 hours.

Table 6. Performance measurements using EC sensor

Hours	Sensor EC	EC-Up
08.00	0.59	On
10.00	1.45	Off
12.00	1.28	Off
14.00	1.32	Off
16.00	1.30	Off

Gambar 16. Performance measurement of EC sensor at 08.00 and 16.00 hours

Table 6 and Figure 16 show that at 08.00 hours the level of EC nutrition is still below 1 so that the EC-Up sensor is On. In this condition, the solenoid valve will open to drain EC water and raise the pH level to above 1. On the other hand, at 10.00, 12.00, 14,000, and 16.00 the EC nutrient level is already above 1 so that the EC-Up sensor is automatically in the Off status.

Table 7. Comparison between prototype hydroponic greenhouse-Arduino-Uno-standalone PV (proposed study) than previous studies

Authors	Methods/ Devices	Ph Level	EC Level	High/ Vol. Level	Temp. Level	Monitored by	Power Supply	Real Time	Green-house
Fitria Hidayanti, et.al. [1]	Arduino Uno	6-7	NA	18-20 cm	NA	LCD Display	Standalone PV-Battery	Yes	No
Helmy, et.al. [2]	Nutrient Film Technique	NA	1.4 mS or 700 ppm	NA	NA	Website	Grid PLN	No	No
Yuga Had-fridar Putra, et. al [3]	Microcontroller NodeMCU esp8266 v3	NA	600-800 ppm	5-10 cm	23^0-27^0 C	Website	Grid PLN	No	No
David Setiawan, et. al. [4]	Nutrient Film Technique	NA	NA	NA	NA	NA	Standalone PV-Battery	No	No
Muhammad Tirto Utomo, et.al [5]	Arduino Uno using Micro-controller ATMega16 U2	6-6.5	NA	6-8 cm	NA	LCD Display	Grid PLN	Yes	No
Muhammad Fakhruzzaini, et. al. [6]	Arduino Uno using Micro-controller ATMega328	5.5-7.5	NA	10-14 cm	NA	LCD 16 × 2 Display	Grid PLN	Yes	No
Ahmad Rifai, et.al. [7]	Arduino Uno using Fuzzy Logic Controller	NA	110-2000 µS/cm	10-100 mL	NA	LCD 16 × 2 Display	Grid PLN	Yes	No
Proposed Study	**Arduino Uno using Micro-controller ATMega328**	**6-7**	**1-2 mS/cm**	**NA**	**NA**	**LCD 20 × 4 Display**	**Standalone PV-Battery**	**Yes**	**Yes**

Note: NA = not available

Table 7 shows the prototype validation of the proposed hydroponic plant monitoring and control model compared to the previous seven prototypes. The parameters observed were pH level, EC level, high or volume water level, temperature level, measurement monitoring, hydroponic power supply, real-time measurement simulation, and the use of a greenhouse in a hydroponic system. In [1], Fitria Hidayanti, et. al have proposed Arduino Uno be supplied by Standalone PV-Battery to control the pH level and nutrient water level which their values monitored in real-time using an LCD. This prototype was able to control the pH level between 6-8 and the nutrition water level between 18-20 cm. In [2], Helmy, et. al. have proposed a Nutrient Film Technique supplied by the Indonesia Electric Company (PLN) grid to control the EC level of 1.4 ms or 700 ppm whose value was monitored wirelessly by the website. In [3], Yuga Hadfridar Putra, et.al have proposed the Arduino Uno be supplied by the PLN Grid to control the EC level, nutrition water high level, temperature, and its value to be monitored wirelessly by the website. This prototype was able to control the EC level between 600-800 ppm, a high level between 5-10 cm, and a temperature level of 23^0-27^0 C. The weakness of the prototype model in [2,3] was that it still used a database so that the measurement of performance parameters on both hydroponic systems still has a time delay. In [4], David Setiawan et.al have proposed Nutrient Film Technique to be supplied by Standalone PV-Battery. The weakness of this prototype only regulated the power supply from the PV-battery to the hydroponic system prototype and was still unable to control and monitor system performance parameters.

In [5], Muhammad Tirto Utomo, et. al proposed Arduino Uno using Microcontroller ATMega16 U2 be supplied by the PLN Grid to control the pH level, nutrient water level, and its value was able to be monitored in real-time using an LCD. This prototype was able to control the pH level between 6-6.5 and the nutrition water level between 6-8 cm. In [6], Muhammad Fakhruzzaini, et. al have proposed Arduino Uno using the ATMega328 Micro-controller supplied by the PLN grid to control the pH level between 5.5-6.5 and the nutrition water level

between 10-14 cm, and the value is monitored in real-time with a 16 × 2 LCD. In [7], Ahmad Rifai, et.al have proposed Arduino Uno using the Fuzzy Logic Controller supplied by the PLN Grid to control the EC level and nutrition water level and its value to be monitored real-time using a 16 × 2 LCD. This prototype was able to control EC levels between 110-2000 µS/cm and nutrition water volume between 10-100 mL. In this study, the authors propose Arduino Uno using a Microcontroller ATMega328 supplied by Standalone PV-Batteries to control pH and EC levels and monitor their values in real-time using a 20 × 4 LCD. This prototype was able to control pH levels between 6-7 and EC levels between 1-2 mS/cm. The advantage of the proposed model is that the character of the LCD is wider so that besides being able to display pH and EC parameter measurements, it is also able to display data on temperature, time, PV voltage, battery voltage, and TDS value. The proposed hydroponic system prototype also has been in the form of a greenhouse to keep the plant growth process taking place in the desired environmental conditions and at the same time preventing attacks from pests and diseases.

IV. CONCLUSION

The prototype model to monitor and control the pH levels and EC nutrition plant supplied by a standalone PV module-connected battery on greenhouse hydroponic systems has been implemented. The two sensors are connected to the Arduino Uno and relay control to drive four pumps, i.e. the water flow pump, EC pump, pH up pump, and pH down pump. The prototype model is able to monitor and control the pH of hydroponic plant water at the level between 6-7 using pH-up and pH-down sensor. This model is also able to monitor and control nutrition plant water over 1 mS/cm using EC sensor. The advantage of the proposed model is that the character of the 20 × 4 LCD is wider so that besides being able to display pH and EC parameter measurements, it is also able to display data on temperature, time, PV voltage, battery voltage, and TDS value. The proposed hydroponic prototype system also has been in the form of a greenhouse to keep the plant growth process taking place in the desired environmental conditions and at the same time preventing attacks from pests and diseases. The implementation of the EC sensor is only able to control the EC value if the value is less than 1 mS/cm. On the other hand, optimal plant growth in a hydroponic greenhouse system requires controlled EC values between 1-2 mS/cm. The use of an EC-down sensor to control the EC value so as not to exceed the 2 mS/cm value is proposed as future work to overcome this problem.

ACKNOWLEDGEMENT

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Lampiran 2.5

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Monitoring and Controlling of pH Levels and Plant Nutrition Supplied by Standalone Photovoltaic in a Greenhouse Hydroponic System using Arduino Uno

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***Abstract* – This paper aims to implement the prototype model to monitor and control the pH levels and nutrition plant (electrical conductivity-EC) supplied by a standalone photovoltaic (PV) module-connected battery (Lithium-Ion) on the greenhouse hydroponic systems. The pH and EC sensors are connected to the Arduino Uno circuit as a relay control to drive four pumps, i.e. the water flow pump, EC pump, pH up pump, and pH down pump. The greenhouse function to control pests and the impact of environmental non-uniformity caused by variation of wind speed, temperature, or sunlight so that hydroponic plants can grow in an appropriate environment. The Arduino Uno circuit with a 20 × 4 liquid crystal display (LCD) order four relays to monitor and control the four pumps of the greenhouse hydroponic system based on the coding which has been programmed previously. The prototype model is able to monitor and control the pH of hydroponic plant water at the level between 6-7 using a pH-up and pH-down sensor. This model is also able to monitor and control nutrition plant water over 1 mS/cm using an EC sensor. Finally, the proposed prototype is able to monitor and control EC and pH level to regulate plant growth in the greenhouse hydroponic system normally and in real-time.**

Keywords: Standalone PV, pH, EC, Greenhouse, Hydroponic, Arduino Uno

I. INTRODUCTION

Recently, hydroponics has become a new method of cultivating plants, especially various types of vegetables or fruit, because they do not require large areas of land and can be done in the yard of the house. The hydroponic method uses a solution of mineral nutrients and water without using soil media for the process of growing and maintaining plants. Hydroponic cultivation in greenhouses is now an option to overcome the constraints of cultivating plants in open areas i.e. attack by pests, wind, temperature, and sunlight which sometimes also interfere with the growth and development of vegetable or fruit plants.

The PV module is a source of electrical power to operate the pH control system and the water level of hydroponic plant nutrients until the harvest period has been implemented in [1]. The proposed prototype was able to control the water pH level of 6-7 and the nutrition solution height of 18-20 cm. This model works when the pH sensor detects below 6 then the solenoid valve at pH-up automatically opens and flows into the nutrition solution. Thus, when the sensor detects a pH of more than 7, the solenoid valve will open and the pH-down solution will flow into the nutrition solution. The solenoid valve will close again when the sensor detects the pH in the range of 6-7. The water level control works when the ultrasonic sensor detects a value of 18 cm, the solenoid valve will open and the nutrition water flows into the nutrition bath, otherwise, the solenoid valve closes again when the sensor detects a value of 20 cm. However, this prototype did not use an EC sensor to detect the level of the nutrition solution in the water. The pH control and nutrient levels are regulated by a solenoid valve, actuated by a water pump, and the power is supplied by the PV module for 24 hours with varying tilt angles.

The EC wireless sensor supplied by Indonesia Electric Company (PLN) grid to monitor and control the concentration of the nutrient solution for hydroponic plant cultivation using two Nutrient Film Technique (NFT) tables based has been proposed in [2]. Each table was installed with monitoring and controlling of nutrition solution concentration devices which transmit the data to server through wireless sensor network. The results showed that the EC-meter sensor was able to read the density of the nutrient solution with a relative error percentage of 3.92%. Node 2 was able to produce a faster threshold data transmission than node 1 with a delay for node 2 of 34.68 seconds and a delay for node 1 of 40.01 seconds. Node 1 was able to result in a better control accuracy of nutrient solution concentration at 96.12% compared to node 2 at 92.79%. The weakness of this model was the performance of monitoring and control depending on temperature and the distance between the node and the coordinator. The higher the system temperature, so its performance also decreases. The farther the distance between the node and the coordinator, the loss of data transmission also will be greater.

The nutritional control, water temperature, water volume, environmental temperature, pH, and humidity on the hydroponic system using the website has been implemented in [3]. The control of this prototype used the NodeMCU esp8266 v3 microcontroller. Data communication between hardware and software used wireless media. Temperature reading system water using the DS18B20 sensor, the water level using the HC-SR04 ultrasonic sensor, and the nutrition level measured by the nutrition solution sensor. This device was designed to be

able to monitor and control the hydroponic system at nutrient temperatures at 23°C-27°C, water height limits 5-10 cm and nutrient levels at the 600-800 ppm limit. The weakness of this research was that it still operates using the website browser menu so that it requires internet access to monitor and control all parameters through this prototype model. The design of PV modules as a power source for DC pump and compared by AC pump to control water flow that supplies nutrients to NFT-type hydroponic plants has been proposed in [4]. This model showed that the use of solar panels and DC pumps to flow water to hydroponic plants is relatively more economical than an AC pump. However, the DC pump was not able to operate continuously, and to overcome this problem then the researchers proposed an AC pump using a DC-AC inverter to drain water in the hydroponic system.

Control of pH and nutrition water levels in the hydroponic system of chili plants using Arduino Uno with microcontroller ATmega16 U2 has been observed in [5]. This prototype was capable of controlling a pH level between 6-6.5 and a nutrition water level between 6-8 cm. The prototype of measuring and controlling water volume and water pH levels in hydroponic system using ultrasonic sensor and pH sensor with Arduino Uno have been proposed in [6]. The proposed system was capable of controlling water level between 10-14 cm and water pH between 5.5-7.5. The prototype of the EC control and water volume on hydroponic system using fuzzy logic has been observed in [7]. Fuzzy logic control using the EC sensor was able to control EC between 110-2000 µS/cm and generate good performance with an average error of 1.91%. This model was also able to control the volume of water between 10-100 mL with an average error of 1.87%. Nevertheless, the drawback of prototype model in [2,3,5,6,7] was completely dependent on grid electricity so that if there is a supply disruption at the source side, the control and monitoring of hydroponic system will not be able to function normally.

This research will implement the prototype model to monitor and control the pH levels and nutrition plant supplied by a 100 watt-peak (Wp) standalone PV panel-connected battery on greenhouse hydroponic systems. The two sensors are connected to the Arduino Uno circuit as a relay control to drive four pumps, i.e. the water flow pump, EC pump, pH up pump, and pH down pump. The greenhouse function to control pests and environmental temperatures so that hydroponic plants can grow in an appropriate environment. The paper is arranged as follows. Chapter II presents the proposed research model, flow chart, PV module concept, greenhouse, Arduino Uno, relay circuit, pH sensor, EC sensor, liquid crystal display (LCD). Chapter III presents the results and discussion i.e. the design of monitoring and control systems for pH and EC levels, measurement and validating the PV and battery module voltages, measurement and validating pH sensor, measurement and validating EC sensor as well as analyzing the performance measurement result of pH sensor and EC sensor in greenhouse hydroponic plant systems. Finally, the paper is concluded in Chapter IV.

II. METHODOLOGY

A. *Research Method*

The monitoring and control system for pH and EC nutrition in the hydroponic greenhouse prototype consists of a combination of hardware and software. The hardware design consists of a PV module, battery (Lithium-Ion), pH sensor, and EC nutrition sensor combined with Arduino Uno software connected to four relays. These relays function to control the water flow pump, nutrient pump (EC), pH-up pump, and pH-down pump. The block diagram of the proposed model can be seen in Figure 1.

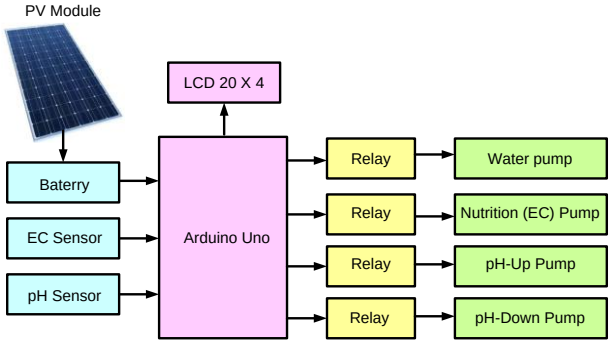


Figure 1. Proposed research model

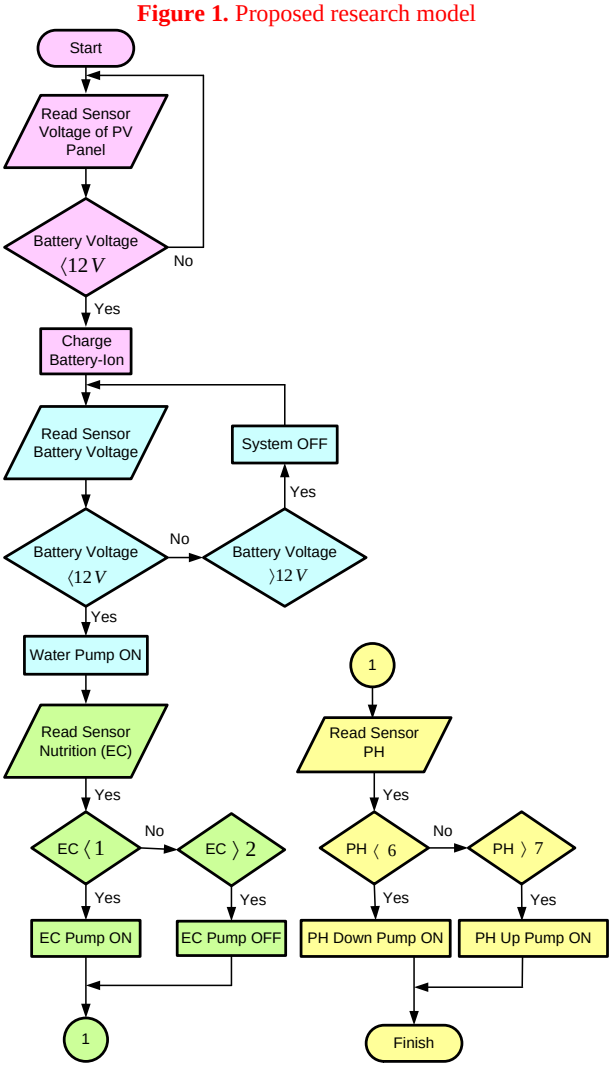


Figure 2. Research flowcart

Figure 1 shows the proposed research model. The 100 Wp standalone photovoltaic (PV) module charges the battery (Lithium-Ion). After the battery is fully charged, the EC sensor and PH sensor will work. The Arduino Uno circuit with a 20 × 4 LCD display will then order four relays i.e. water flow pump, nutrient (EC) pump, pH-up pump, and pH-down pump to work to control the hydroponic system in a greenhouse based on the coding which has been written previously on Arduino-Uno. Figure 2 shows the research flowchart. The research starts with the sensor reading the PV module output voltage. If the battery voltage is less than 12 V, the PV power will charge previously the battery. Then, the battery voltage sensor will work logically if the battery voltage is less than 12 V, then the water flow pump will work. Whereas if the battery voltage exceeds 12 V, the system will shut down. After the water pump starts, the nutrition sensor (EC) will work logically if the EC is less than 1 then the EC pump will turn On and if the EC is greater than 2 then the EC pump will turn Off. Furthermore, the pH sensor works to monitor the pH level of the water. If the pH level is below 7 then the PH pump down will work (On), conversely if the pH level is above 7 then the pH up pump will work (On).

B. Modelling Photovoltaic

The equivalent circuit of PV is shown in Figure 3. It consists of several PV cells which have external connections in series, parallel, or series-parallel [5].

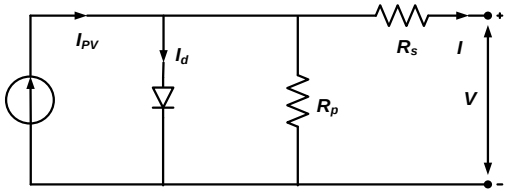


Figure 3. Equivalent circuit of PV panel

The V-I characteristic is shown in Eq. (1):

$$I = I_{PV} - I_o \left[exp\left(\frac{V+R_S I}{a\, V_t}\right) - 1 \right] - \frac{V+R_S I}{R_P} \qquad (1)$$

Where I_{PV} is PV current, I_o is saturated re-serve current, 'a' is the ideal diode constant, $V = N_S K T q^{-1}$ is the thermal voltage, N_S is a number of series cells, q is the electron charge, K is Boltzmann constant, T is temperature pn junction, R_S and R_P are series and parallel resistance of solar panels. I_{PV} has a linear relationship with light intensity and also varies with temperature variations. I_o is a dependent value on the temperature variation. Eq. (2) and Eq. (3) are the calculation of I_{PV} and I_o values:

$$I_{PV} = \left(I_{PV,n} + K_I \Delta T\right) \frac{G}{G_n} \qquad (2)$$

$$I_o = \frac{I_{SC,n} + K_I \Delta T}{exp\,(V_{OC,n} + K_V \Delta T)/aV_t - 1} \qquad (3)$$

Where, $I_{PV,n}$, $I_{SC,n}$, and $V_{OC,n}$ are the photovoltaic current, short circuit current, and open-circuit voltage under standard conditions ($T_n = 25^0 C$ and $G_n = 1000\, W/m^2$), respectively. The K_I value is the coefficient of short circuit current to temperature, $\Delta T = T - T_n$ is temperature deviation from standard temperature, G is the light intensity and K_V is coefficient of open-circuit voltage ratio to temperature. Open circuit voltage, short circuit current, and voltage-current related to maximum power are three important values of I-V characteristics of PV panel. These points are changed by variation in atmospheric conditions. By using Eq. (4) and Eq. (5) derived from the PV model equation, short-circuit current and open-circuit voltage can be calculated under different atmospheric conditions.

$$I_{SC} = (I_{SC} + K_I \Delta T) \frac{G}{G_n} \qquad (4)$$

$$V_{OC} = (V_{OC} + K_V \Delta T) \qquad (5)$$

C. Green House

The greenhouse is a frame or corrugated building covered with a clear or translucent material that can transmit light optimally for production and protect plants from climatic conditions that are detrimental to plant growth. The cultivating of plants in a greenhouse has the advantage of a more controlled microenvironment and uniformity of production for each plant. The functions of a greenhouse include managing plant growth schedules, increasing production yields, minimizing pesticides, increasing production quality, assets, and performance, as well as a means of agro-tourism [6].

D. Arduino Uno

Arduino-Uno is an electronic board containing an ATMega328 microcontroller, which is a chip that functionally acts like a computer. This device is used to realize electronic circuits from simple to complex. LED control to robot control can be implemented using this relatively small board. In the health sector with the addition of certain components, this tool can be used to monitor the condition of patients in the hospital and control equipment at home [7]. Figure 4 shows the Arduino Uno model.

Figure 4. Arduino Uno model

E. Relay Circuit

The relay circuit is a link between the Arduino Uno circuit with the water flow pump, nutrient pump (EC), pH-up pump, and pH-down pump to work on controlling the greenhouse hydroponic system based on the coding previously programmed on Arduino-Nano. Figure 5 shows a relay circuit on the greenhouse hydroponic system.

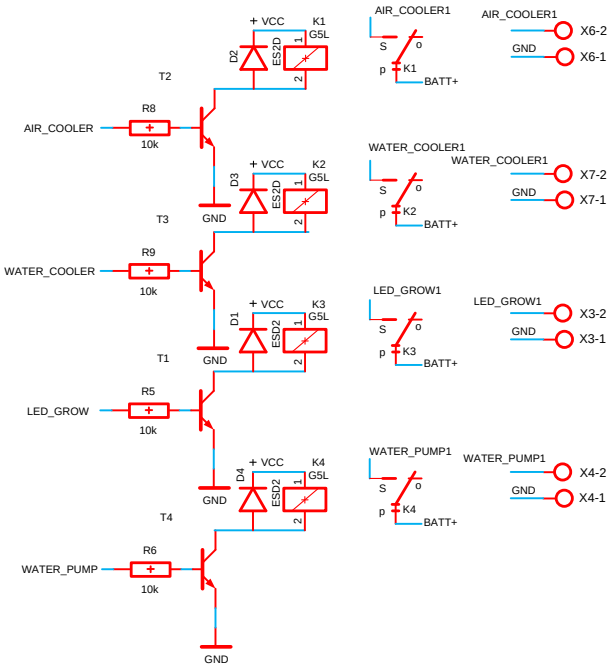


Figure 5. Relay circuit

F. Sensor Electrical Conductivity

The Electrical Conductivity (EC) sensor is used to measure the concentration of a solution for example hydroponic nutrient solution which is expressed in units of miliSiemens per centimeter (mS/cm). The EC-meter is an alternative measurement device to the Total Dissolved Solids (TDS)-meter to measure the concentration of a hydroponic nutrient solution expressed in units of parts per million (ppm) [8]. The EC value affects the rate of nutrition absorption by plants, the greater the EC value, the faster the absorption of nutrition by plants and vice versa if the EC value is smaller, the absorption of nutrition will be slow [9]. The series of EC sensors installed in the greenhouse hydroponic system is connected to the Arduino-Uno, using the IDE software and libraries in the Arduino Uno. Figure 6 shows the EC sensor circuit.

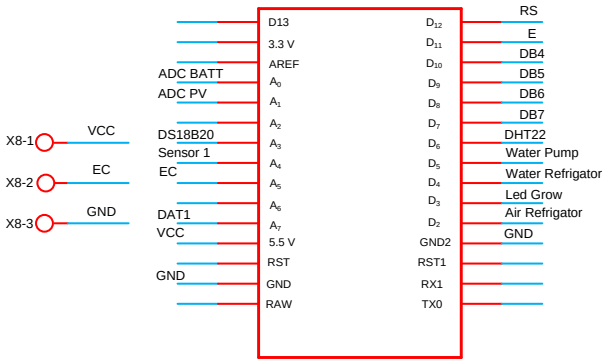


Figure 6. EC sensor circuit

G. Sensor pH

The pH sensor is an instrument for measuring the concentration of hydrogen in a solution. The pH sensors for water and for soil need to be calibrated periodically so that the accuracy of the measurement is guaranteed. The series of pH sensors installed in the greenhouse hydroponic system is connected to the Arduino-Uno, using the IDE software and libraries in the Arduino Uno. The pH sensor circuit is shown in Figure 7.

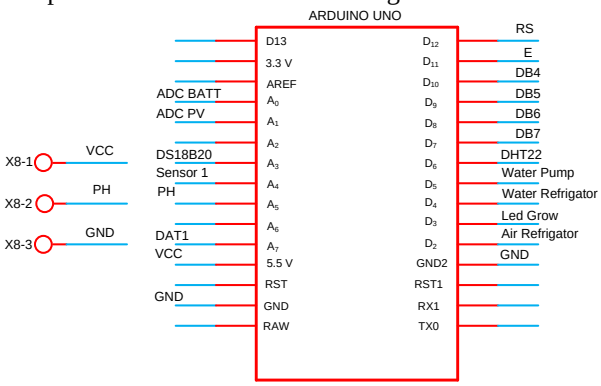


Figure 7. The pH sensor circuit

H. Liquid Crystal Display

Liquid Crystal Display (LCD) is a type of display media that uses liquid crystals as the main display. LCD has been used in various fields, for example in electronic devices, such as televisions, calculators, or computer screens. The LCD circuit that is installed with a greenhouse hydroponic is connected to the Arduino-Uno, using the IDE software and libraries in the Arduino Uno. Figure 8 shows the LCD circuit.

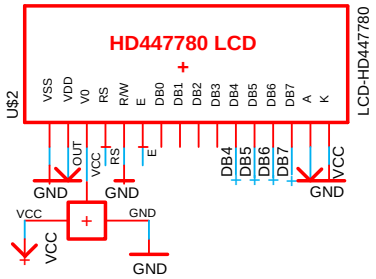
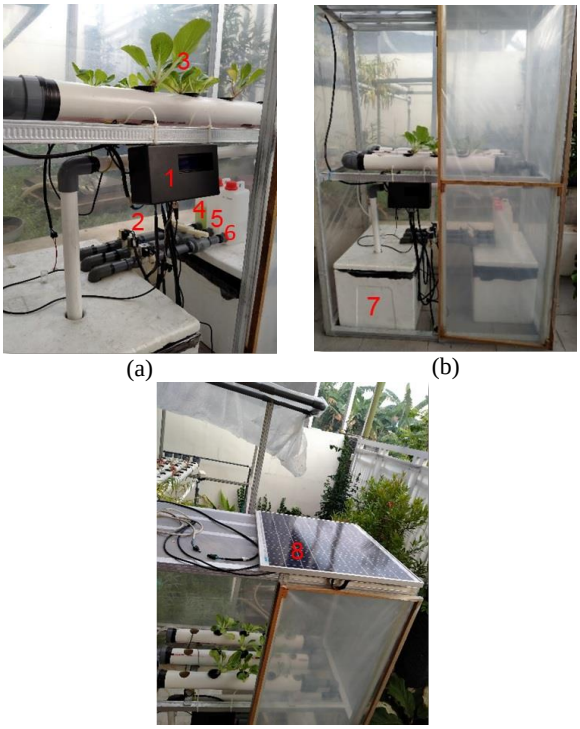


Figure 8. LCD circuit

III. Results and Discussion

Figure 9 shows the implementation of a monitoring system for pH and plant nutrition in a greenhouse hydroponic system using Arduino Uno. Figure 9.a shows (1) Arduino-Uno Controller, (2) Solenoid Valve, (3) Hydroponic Plant, (4) Nutrition EC, (5) pH-up, and (6) pH-down. Figure 9.b. shows nutrient water and sensors. Figure 9.c shows the PV module connected to a battery (Lithium-Ion). The working mechanism of this prototype is started by the sensors read the output voltage of the PV module. If the battery voltage is less than 12 V, the PV output power will charge the battery. In this condition, the battery voltage sensor will work and the water pump will also work. After the water pump starts then the EC sensor also works, with logic if the EC level is greater than 1 then the EC pump will turn on and if the EC level is less than 2 then the EC pump will shut down. Furthermore, the pH sensor works to monitor the PH level of the water. If the PH level is below 7 then the PH-down pump will work (On), otherwise if the pH level is above 7 then the pH-up pump will work (On). To obtain better monitoring and control system performance,

a number of validation measurements are carried out i.e. PV voltage, battery voltage, EC sensor, and pH sensor.



(a) (b)

(c)

Figure 9. Implementation of a monitoring system for pH and plant nutrition in a greenhouse hydroponic system

Table 1. Measurement of PV voltage

No.	Volt Meter (V)	PV Voltage Sensor (V)	Error (%)
1	5.00	5.07	1.400
2	7.00	7.10	1.429
3	9.00	9.09	1.000
4	12.00	12.08	0.667

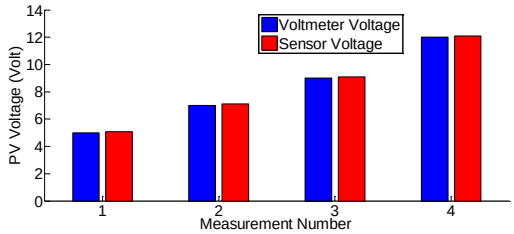


Figure 10. Measurement of PV voltage

Table 1 and Figure 10 show the PV voltage measurement using a voltmeter and a PV voltage sensor. The first measurement with a voltmeter produces a PV voltage of 5 V, while the measurement uses a sensor as 5.07 V. The fourth measurement with a voltmeter produces a PV voltage of 12 V, while the measurement uses a sensor as 12.08 V. The four measurement results show that the PV voltage sensor produces a measurement accuracy close to the same compared to measurements using a voltmeter with a maximum error of 1.429% or already below 5%.

Table 2 and Figure 11 show the battery voltage measurement using a voltmeter and a battery voltage sensor. The first measurement with a voltmeter produces a PV voltage of 5 V, while the measurement using a sensor resulting of 5.10 V. The fourth measurement with a voltmeter produces a PV voltage of 12 V, while the measurement using a sensor resulting of 12.07 V.

Table 2. Measurement of battery voltage

No.	Volt Meter (V)	Battery Voltage Sensor (V)	Error (%)
1	5.00	5.10	2.000
2	7.00	7.06	0.857
3	9.00	9.09	1.000
4	12.00	12.07	0.583

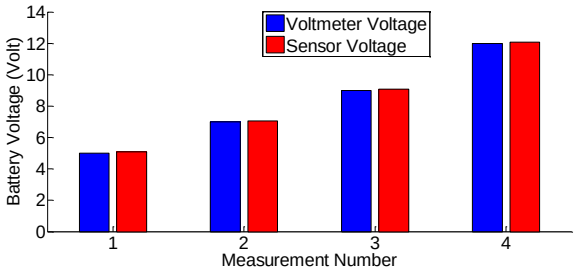


Figure 11. Measurement of battery voltage

The four measurements on Table 2 and Figure 11 show that the battery voltage sensor produces a measurement accuracy close to the same compared to measurements using a battery with a maximum error of 2% or already below 5%. PH sensor measurements are carried out to ensure the sensor can run properly because it can affect pH measurements when monitoring equipment is applied to hydroponic plants in greenhouse. Figure 12 shows pH measurements using a digital pH-meter. Figure 13 shows pH measurements using a pH sensor. Table 3 shows the measurements of water pH using a digital pH meter and pH sensor. Figure 13 shows the comparison of the pH of the water using a digital-meter and sensor.

Figure 12. pH measurement using digital-meter

Figure 13. pH measurement using sensor

Table 3 Measurements of water pH using a digital pH meter and pH sensor

No.	PH Water	Digital PH meter	Error (%)	Sensor PH	Error (%)
1	4.00	4.0	0	4.33	8.250
2	6.86	6.8	0.875	6.76	1.458

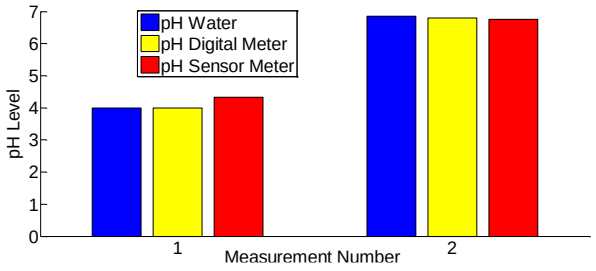


Figure 14. Comparison of the pH water using a digital-meter and sensor

Table 3 and Figure 14 show that on first measurement the pH value of water is 4, read by digital pH meter and pH sensor of 4.0 and 4.33, respectively. Otherwise, on the second measurement shows that the pH value of the water is 6.86, which is read by a digital pH meter and a pH sensor of 6.8 and 6.76, respectively. Table 3 shows that measurements using a digital pH meter and a pH sensor are able to give close to the same results. The measurement results of digital pH meter with water pH below 6 is accurate because they produce an error of 0%. Then, the measurement of pH digital meter with water pH values between 6-7 is relatively accurate because it produces an error of 0.875% or is already below 5%.

Table 3 and Figure 14 also show that on the first measurement results of pH sensors with water pH below 6 are still inaccurate because they produce an error of 8.250%. However, on the second measurement of pH sensors with water pH values between 6-7 is relatively accurate because it produces an error of 1.458% or is already below 5%. EC sensor measurements are carried out to ensure the nutrition sensor is functioning properly, because this indicator will affect the EC measurement of the water when the monitoring system is running. Table 4 shows the measurement of nutrition levels using the TDS sensor and the EC sensor.

Table 4. Nutrition measurement using TDS and EC sensors

No.	Digital TDS (ppm)	Sensor TDS (ppm)	Sensor EC (mS/cm)
1	450	458	1.23
2	540	542	1.45
3	760	765	2.05
4	880	882	2.30

The performance measurement of the pH monitoring system is carried out to ensure that the pH of the water can be controlled to a degree of acidity between 6-7. This range of values is needed to keep hydroponic plant growth relatively stable. The measurements are made on a hydroponic plant monitoring system, using a relay that functions to run the pH pump motor. The function of pH-Up and pH-Down is to keep the pH of hydroponic plant water at the level of 6-7. Table 5 shows the performance measurements of the pH sensor. Figure 15 shows the measurement of pH-Up performance at 08.00 and 14.00 hours.

Table 5. Performance measurement using pH sensor

Hours	Sensor pH	pH-Up	pH-Down
08.00	4.33	On	Off
10.00	6.45	Off	Off
12.00	6.76	Off	Off
14.00	7.32	Off	On
16.00	6.47	Off	Off

Figure 15. Performance measurement of pH-Up at 08.00 and 14.00 hours

Table 5 and Figure 15 show that at 08.00 the pH level is below 6 so that the pH-Up sensor is on. In this condition, the solenoid valve will open to drain pH-Up water so that the pH value rises to above 6. On the other hand, at 10.00, 12.00, 14.00, and 16.00 the pH level is above 6 so that the pH-Up sensor is in the Off status. Table 5 and Figure 15 also show that at 14.00 hours the pH level is above 7 so that the pH-down sensor is On. In this condition, the solenoid valve will open to drain pH-down water to lower the pH value to below 7. On the other hand, at 08.00, 10.00, 12.00, and 16.00 hours the pH level are already below 7 so that the pH-down sensor is automatically in the Off status.

The performance measurement of EC is carried out to ensure that the water nutrition concentration can be controlled within a value range of 1-2 mS/cm. The EC control is needed to keep hydroponic plant growth relatively stable. The measurements are made on the hydroponic plant monitoring system, using a relay that functions to run the EC pump motor. Table 6 shows the performance measurements using an EC sensor. Figure 15 shows the measurement of EC at 08.00 and 16.00 hours.

Table 6. Performance measurements using EC sensor

Hours	Sensor EC	EC-Up
08.00	0.59	On
10.00	1.45	Off
12.00	1.28	Off
14.00	1.32	Off
16.00	1.30	Off

Gambar 16. Performance measurement of EC sensor at 08.00 and 16.00 hours

Table 6 and Figure 16 show that at 08.00 hours the level of EC nutrition is still below 1 so that the EC-Up sensor is On. In this condition, the solenoid valve will open to drain EC water and raise the pH level to above 1. On the other hand, at 10.00, 12.00, 14,000, and 16.00 the EC nutrient level is already above 1 so that the EC-Up sensor is automatically in the Off status.

Table 7. Comparison between prototype hydroponic greenhouse-Arduino-Uno-standalone PV (proposed study) than previous studies

Authors	Methods/ Devices	Ph Level	EC Level	High/ Vol. Level	Temp. Level	Monitored by	Power Supply	Real Time	Green-house
Fitria Hidayanti, et.al. [1]	Arduino Uno	6-7	NA	18-20 cm	NA	LCD Display	Standalone PV-Battery	Yes	No
Helmy, et.al. [2]	Nutrient Film Technique	NA	1.4 mS or 700 ppm	NA	NA	Website	Grid PLN	No	No
Yuga Had-fridar Putra, et. al [3]	Microcontroller NodeMCU esp8266 v3	NA	600-800 ppm	5-10 cm	23^0-27^0 C	Website	Grid PLN	No	No
David Setiawan, et. al. [4]	Nutrient Film Technique	NA	NA	NA	NA	NA	Standalone PV-Battery	No	No
Muhammad Tirto Utomo, et.al [5]	Arduino Uno using Micro-controller ATMega16 U2	6-6.5	NA	6-8 cm	NA	LCD Display	Grid PLN	Yes	No
Muhammad Fakhruzzaini, et. al. [6]	Arduino Uno using Micro-controller ATMega328	5.5-7.5	NA	10-14 cm	NA	LCD 16 × 2 Display	Grid PLN	Yes	No
Ahmad Rifai, et.al. [7]	Arduino Uno using Fuzzy Logic Controller	NA	110-2000 µS/cm	10-100 mL	NA	LCD 16 × 2 Display	Grid PLN	Yes	No
Proposed Study	**Arduino Uno using Micro-controller ATMega328**	**6-7**	**1-2 mS/cm**	**NA**	**NA**	**LCD 20 × 4 Display**	**Standalone PV-Battery**	**Yes**	**Yes**

Note: NA = not available

Table 7 shows the prototype validation of the proposed hydroponic plant monitoring and control model compared to the previous seven prototypes. The parameters observed were pH level, EC level, high or volume water level, temperature level, measurement monitoring, hydroponic power supply, real-time measurement simulation, and the use of a greenhouse in a hydroponic system. In [1], Fitria Hidayanti, et. al have proposed Arduino Uno be supplied by Standalone PV-Battery to control the pH level and nutrient water level which their values monitored in real-time using an LCD. This prototype was able to control the pH level between 6-8 and the nutrition water level between 18-20 cm. In [2], Helmy, et. al. have proposed a Nutrient Film Technique supplied by the Indonesia Electric Company (PLN) grid to control the EC level of 1.4 ms or 700 ppm whose value was monitored wirelessly by the website. In [3], Yuga Hadfridar Putra, et.al have proposed the Arduino Uno be supplied by the PLN Grid to control the EC level, nutrition water high level, temperature, and its value to be monitored wirelessly by the website. This prototype was able to control the EC level between 600-800 ppm, a high level between 5-10 cm, and a temperature level of 23^0-27^0 C. The weakness of the prototype model in [2,3] was that it still used a database so that the measurement of performance parameters on both hydroponic systems still has a time delay. In [4], David Setiawan et.al have proposed Nutrient Film Technique to be supplied by Standalone PV-Battery. The weakness of this prototype only regulated the power supply from the PV-battery to the hydroponic system prototype and was still unable to control and monitor system performance parameters.

In [5], Muhammad Tirto Utomo, et. al proposed Arduino Uno using Microcontroller ATMega16 U2 be supplied by the PLN Grid to control the pH level, nutrient water level, and its value was able to be monitored in real-time using an LCD. This prototype was able to control the pH level between 6-6.5 and the nutrition water level between 6-8 cm. In [6], Muhammad Fakhruzzaini, et. al have proposed Arduino Uno using the ATMega328 Micro-controller supplied by the PLN grid to control the pH level between 5.5-6.5 and the nutrition water level

between 10-14 cm, and the value is monitored in real-time with a 16 × 2 LCD. In [7], Ahmad Rifai, et.al have proposed Arduino Uno using the Fuzzy Logic Controller supplied by the PLN Grid to control the EC level and nutrition water level and its value to be monitored real-time using a 16 × 2 LCD. This prototype was able to control EC levels between 110-2000 µS/cm and nutrition water volume between 10-100 mL. In this study, the authors propose Arduino Uno using a Microcontroller ATMega328 supplied by Standalone PV-Batteries to control pH and EC levels and monitor their values in real-time using a 20 × 4 LCD. This prototype was able to control pH levels between 6-7 and EC levels between 1-2 mS/cm. The advantage of the proposed model is that the character of the LCD is wider so that besides being able to display pH and EC parameter measurements, it is also able to display data on temperature, time, PV voltage, battery voltage, and TDS value. The proposed hydroponic system prototype also has been in the form of a greenhouse to keep the plant growth process taking place in the desired environmental conditions and at the same time preventing attacks from pests and diseases.

IV. CONCLUSION

The prototype model to monitor and control the pH levels and EC nutrition plant supplied by a standalone PV module-connected battery on greenhouse hydroponic systems has been implemented. The two sensors are connected to the Arduino Uno and relay control to drive four pumps, i.e. the water flow pump, EC pump, pH up pump, and pH down pump. The prototype model is able to monitor and control the pH of hydroponic plant water at the level between 6-7 using pH-up and pH-down sensor. This model is also able to monitor and control nutrition plant water over 1 mS/cm using EC sensor. The advantage of the proposed model is that the character of the 20 × 4 LCD is wider so that besides being able to display pH and EC parameter measurements, it is also able to display data on temperature, time, PV voltage, battery voltage, and TDS value. The proposed hydroponic prototype system also has been in the form of a greenhouse to keep the plant growth process taking place in the desired environmental conditions and at the same time preventing attacks from pests and diseases. The implementation of the EC sensor is only able to control the EC value if the value is less than 1 mS/cm. On the other hand, optimal plant growth in a hydroponic greenhouse system requires controlled EC values between 1-2 mS/cm. The use of an EC-down sensor to control the EC value so as not to exceed the 2 mS/cm value is proposed as future work to overcome this problem.

ACKNOWLEDGEMENT

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Lampiran 2.6

Hasil revisi penulis terhadap review pertama dan kedua

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Monitoring and Controlling of pH Levels and Plant Nutrition Supplied by Standalone Photovoltaic in a Greenhouse Hydroponic System using Arduino Uno

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***Abstract* – This paper aims to implement the prototype model to monitor and control the pH levels and nutrition plant (electrical conductivity-EC) supplied by a standalone photovoltaic (PV) module-connected battery (Lithium-Ion) on the greenhouse hydroponic systems. The pH and EC sensors are connected to the Arduino Uno circuit as a relay control to drive four pumps, i.e. the water flow pump, EC pump, pH up pump, and pH down pump. The greenhouse function to control pests and the impact of environmental non-uniformity caused by variation of wind speed, temperature, or sunlight so that hydroponic plants can grow in an appropriate environment. The Arduino Uno circuit with a 20 × 4 liquid crystal display (LCD) order four relays to monitor and control the four pumps of the greenhouse hydroponic system based on the coding which has been programmed previously. The prototype model is able to monitor and control the pH of hydroponic plant water at the level between 6-7 using a pH-up and pH-down sensor. This model is also able to monitor and control nutrition plant water over 1 mS/cm using an EC sensor. Finally, the proposed prototype is able to monitor and control EC and pH level to regulate plant growth in the greenhouse hydroponic system normally and in real-time.**

Keywords: Standalone PV, pH, EC, Greenhouse, Hydroponic, Arduino Uno

I. INTRODUCTION

Recently, hydroponics has become a new method of cultivating plants, especially various types of vegetables or fruit, because they do not require large areas of land and can be done in the yard of the house. The hydroponic method uses a solution of mineral nutrients and water without using soil media for the process of growing and maintaining plants. Hydroponic cultivation in greenhouses is now an option to overcome the constraints of cultivating plants in open areas i.e. attack by pests, wind, temperature, and sunlight which sometimes also interfere with the growth and development of vegetable or fruit plants.

The PV module is a source of electrical power to operate the pH control system and the water level of hydroponic plant nutrients until the harvest period has been implemented in [1]. The proposed prototype was able to control the water pH level of 6-7 and the nutrition solution height of 18-20 cm. This model works when the pH sensor detects below 6 then the solenoid valve at pH-up automatically opens and flows into the nutrition solution. Thus, when the sensor detects a pH of more than 7, the solenoid valve will open and the pH-down solution will flow into the nutrition solution. The solenoid valve will close again when the sensor detects the pH in the range of 6-7. The water level control works when the ultrasonic sensor detects a value of 18 cm, the solenoid valve will open and the nutrition water flows into the nutrition bath, otherwise, the solenoid valve closes again when the sensor detects a value of 20 cm. However, this prototype did not use an EC sensor to detect the level of the nutrition solution in the water. The pH control and nutrient levels are regulated by a solenoid valve, actuated by a water pump, and the power is supplied by the PV module for 24 hours with varying tilt angles.

The EC wireless sensor supplied by Indonesia Electric Company (PLN) grid to monitor and control the concentration of the nutrient solution for hydroponic plant cultivation using two Nutrient Film Technique (NFT) tables based has been proposed in [2]. Each table was installed with monitoring and controlling of nutrition solution concentration devices which transmit the data to server through wireless sensor network. The results showed that the EC-meter sensor was able to read the density of the nutrient solution with a relative error percentage of 3.92%. Node 2 was able to produce a faster threshold data transmission than node 1 with a delay for node 2 of 34.68 seconds and a delay for node 1 of 40.01 seconds. Node 1 was able to result in a better control accuracy of nutrient solution concentration at 96.12% compared to node 2 at 92.79%. The weakness of this model was the performance of monitoring and control depending on temperature and the distance between the node and the coordinator. The higher the system temperature, so its performance also decreases. The farther the distance between the node and the coordinator, the loss of data transmission also will be greater.

The nutritional control, water temperature, water volume, environmental temperature, pH, and humidity on the hydroponic system using the website has been implemented in [3]. The control of this prototype used the NodeMCU esp8266 v3 microcontroller. Data communication between hardware and software used wireless media. Temperature reading system water using the DS18B20 sensor, the water level using the HC-SR04 ultrasonic sensor, and the nutrition level measured by the nutrition solution sensor. This device was designed to be

able to monitor and control the hydroponic system at nutrient temperatures at 23°C-27°C, water height limits 5-10 cm and nutrient levels at the 600-800 ppm limit. The weakness of this research was that it still operates using the website browser menu so that it requires internet access to monitor and control all parameters through this prototype model. The design of PV modules as a power source for DC pump and compared by AC pump to control water flow that supplies nutrients to NFT-type hydroponic plants has been proposed in [4]. This model showed that the use of solar panels and DC pumps to flow water to hydroponic plants is relatively more economical than an AC pump. However, the DC pump was not able to operate continuously, and to overcome this problem then the researchers proposed an AC pump using a DC-AC inverter to drain water in the hydroponic system.

Control of pH and nutrition water levels in the hydroponic system of chili plants using Arduino Uno with microcontroller ATmega16 U2 has been observed in [5]. This prototype was capable of controlling a pH level between 6-6.5 and a nutrition water level between 6-8 cm. The prototype of measuring and controlling water volume and water pH levels in hydroponic system using ultrasonic sensor and pH sensor with Arduino Uno have been proposed in [6]. The proposed system was capable of controlling water level between 10-14 cm and water pH between 5.5-7.5. The prototype of the EC control and water volume on hydroponic system using fuzzy logic has been observed in [7]. Fuzzy logic control using the EC sensor was able to control EC between 110-2000 µS/cm and generate good performance with an average error of 1.91%. This model was also able to control the volume of water between 10-100 mL with an average error of 1.87%. Nevertheless, the drawback of prototype model in [2,3,5,6,7] was completely dependent on grid electricity so that if there is a supply disruption at the source side, the control and monitoring of hydroponic system will not be able to function normally.

This research will implement the prototype model to monitor and control the pH levels and nutrition plant supplied by a 100 watt-peak (Wp) standalone PV panel-connected battery on greenhouse hydroponic systems. The two sensors are connected to the Arduino Uno circuit as a relay control to drive four pumps, i.e. the water flow pump, EC pump, pH up pump, and pH down pump. The greenhouse function to control pests and environmental temperatures so that hydroponic plants can grow in an appropriate environment. The paper is arranged as follows. Chapter II presents the proposed research model, flow chart, PV module concept, greenhouse, Arduino Uno, relay circuit, pH sensor, EC sensor, liquid crystal display (LCD). Chapter III presents the results and discussion i.e. the design of monitoring and control systems for pH and EC levels, measurement and validating the PV and battery module voltages, measurement and validating pH sensor, measurement and validating EC sensor as well as analyzing the performance measurement result of pH sensor and EC sensor in greenhouse hydroponic plant systems. Finally, the paper is concluded in Chapter IV.

II. METHODOLOGY

A. *Research Method*

The monitoring and control system for pH and EC nutrition in the hydroponic greenhouse prototype consists of a combination of hardware and software. The hardware design consists of a PV module, battery (Lithium-Ion), pH sensor, and EC nutrition sensor combined with Arduino Uno software connected to four relays. These relays function to control the water flow pump, nutrient pump (EC), pH-up pump, and pH-down pump. The block diagram of the proposed model can be seen in Figure 1.

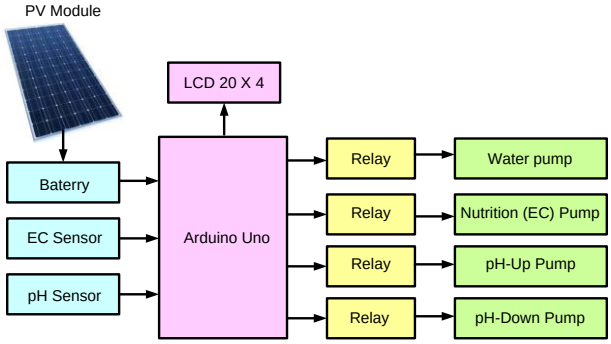


Figure 1. Proposed research model

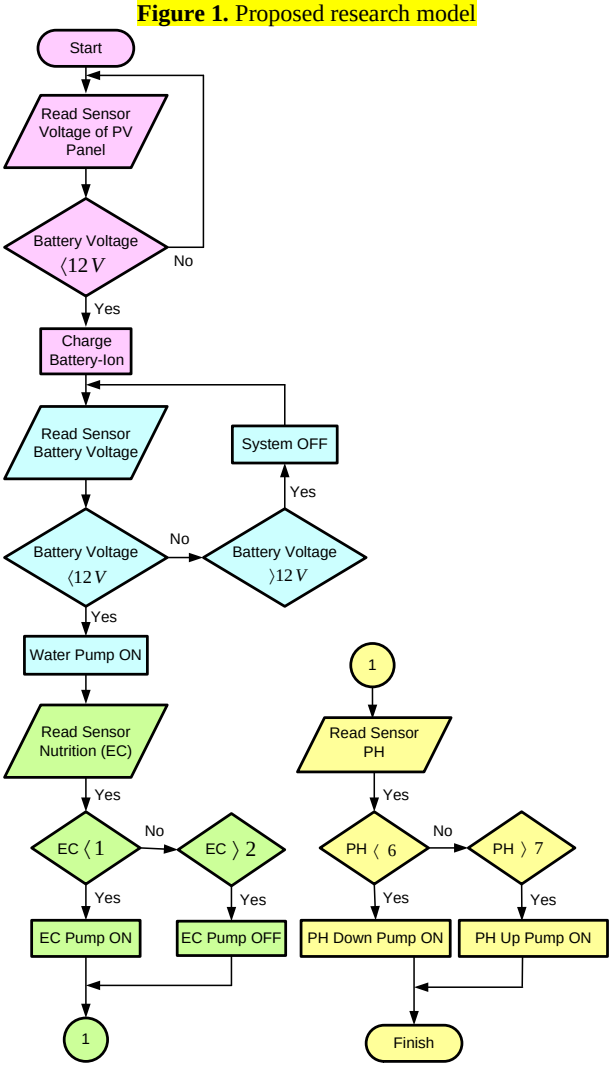


Figure 2. Research flowcart

Figure 1 shows the proposed research model. This proposed model is called the monitoring system for pH and plant nutrition in a greenhouse hydroponic system using Arduino Uno. The 100 Wp standalone photovoltaic (PV) module charges the battery (Lithium-Ion). After the battery is fully charged, the EC sensor and PH sensor will work. The Arduino Uno circuit with a 20 × 4 LCD display will then order four relays i.e. water flow pump, nutrient (EC) pump, pH-up pump, and pH-down pump to work to control the hydroponic system in a greenhouse based on the coding which has been written previously on Arduino-Uno. Figure 2 shows the research flowchart. The research starts with the sensor reading the PV module output voltage. If the battery voltage is less than 12 V, the PV power will charge previously the battery. Then, the battery voltage sensor will work logically if the battery voltage is less than 12 V, then the water flow pump will work. Whereas if the battery voltage exceeds 12 V, the system will shut down. After the water pump starts, the nutrition sensor (EC) will work logically if the EC is less than 1 then the EC pump will turn On and if the EC is greater than 2 then the EC pump will turn Off. Furthermore, the pH sensor works to monitor the pH level of the water. If the pH level is below 7 then the PH pump down will work (On), conversely if the pH level is above 7 then the pH up pump will work (On).

B. *Modelling Photovoltaic*

The equivalent circuit of PV is shown in Figure 3. It consists of several PV cells which have external connections in series, parallel, or series-parallel [5].

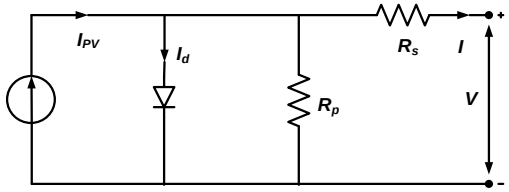


Figure 3. Equivalent circuit of PV panel

The V-I characteristic is shown in Eq. (1):

$$I = I_{PV} - I_o \left[exp\left(\frac{V+R_S I}{a\,V_t}\right) - 1 \right] - \frac{V+R_S I}{R_P} \qquad (1)$$

Where I_{PV} is PV current, I_o is saturated re-serve current, 'a' is the ideal diode constant, $V = N_S K T q^{-1}$ is the thermal voltage, N_S is a number of series cells, q is the electron charge, K is Boltzmann constant, T is temperature pn junction, R_S and R_P are series and parallel resistance of solar panels. I_{PV} has a linear relationship with light intensity and also varies with temperature variations. I_o is a dependent value on the temperature variation. Eq. (2) and Eq. (3) are the calculation of I_{PV} and I_o values:

$$I_{PV} = \left(I_{PV,n} + K_I \Delta T\right) \frac{G}{G_n} \qquad (2)$$

$$I_o = \frac{I_{SC,n} + K_I \Delta T}{exp\,(V_{OC,n} + K_V \Delta T)/aV_t - 1} \qquad (3)$$

Where, $I_{PV,n}$, $I_{SC,n}$, and $V_{OC,n}$ are the photovoltaic current, short circuit current, and open-circuit voltage under standard conditions ($T_n = 25^0 C$ and $G_n = 1000\,W/m^2$), respectively. The K_I value is the coefficient of short circuit current to temperature, $\Delta T = T - T_n$ is temperature deviation from standard temperature, G is the light intensity and K_V is coefficient of open-circuit voltage ratio to temperature. Open circuit voltage, short circuit current, and voltage-current related to maximum power are three important values of I-V characteristics of PV panel. These points are changed by variation in atmospheric conditions. By using Eq. (4) and Eq. (5) derived from the PV model equation, short-circuit current and open-circuit voltage can be calculated under different atmospheric conditions.

$$I_{SC} = (I_{SC} + K_I \Delta T) \frac{G}{G_n} \qquad (4)$$

$$V_{OC} = (V_{OC} + K_V \Delta T) \qquad (5)$$

C. *Green House*

The greenhouse is a frame or corrugated building covered with a clear or translucent material that can transmit light optimally for production and protect plants from climatic conditions that are detrimental to plant growth. The cultivating of plants in a greenhouse has the advantage of a more controlled microenvironment and uniformity of production for each plant. The functions of a greenhouse include managing plant growth schedules, increasing production yields, minimizing pesticides, increasing production quality, assets, and performance, as well as a means of agro-tourism [6].

D. *Arduino Uno*

Arduino-Uno is an electronic board containing an ATMega328 microcontroller, which is a chip that functionally acts like a computer. This device is used to realize electronic circuits from simple to complex. LED control to robot control can be implemented using this relatively small board. In the health sector with the addition of certain components, this tool can be used to monitor the condition of patients in the hospital and control equipment at home [7]. Figure 4 shows the Arduino Uno model.

Figure 4. Arduino Uno model

E. *Relay Circuit*

The relay circuit is a link between the Arduino Uno circuit with the water flow pump, nutrient pump (EC), pH-up pump, and pH-down pump to work on controlling the greenhouse hydroponic system based on the coding previously programmed on Arduino-Nano. Figure 5 shows a relay circuit on the greenhouse hydroponic system.

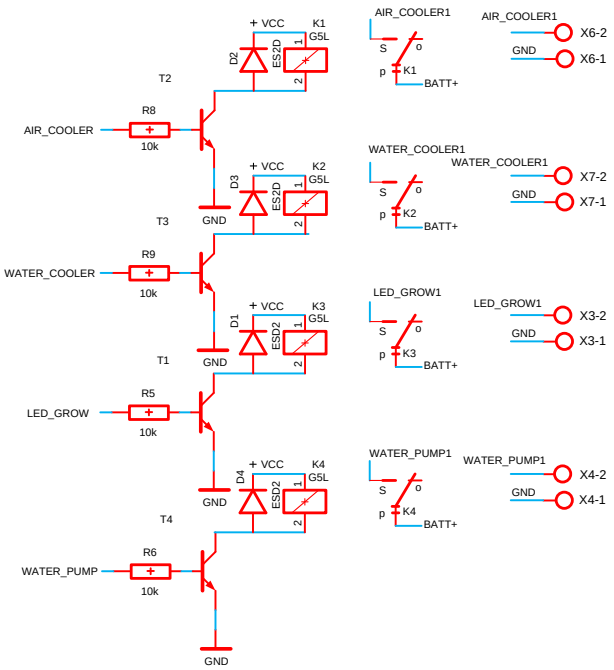


Figure 5. Relay circuit

F. *Sensor Electrical Conductivity*

The Electrical Conductivity (EC) sensor is used to measure the concentration of a solution for example hydroponic nutrient solution which is expressed in units of miliSiemens per centimeter (mS/cm). The EC-meter is an alternative measurement device to the Total Dissolved Solids (TDS)-meter to measure the concentration of a hydroponic nutrient solution expressed in units of parts per million (ppm) [8]. The EC value affects the rate of nutrition absorption by plants, the greater the EC value, the faster the absorption of nutrition by plants and vice versa if the EC value is smaller, the absorption of nutrition will be slow [9]. The series of EC sensors installed in the greenhouse hydroponic system is connected to the Arduino-Uno, using the IDE software and libraries in the Arduino Uno. Figure 6 shows the EC sensor circuit.

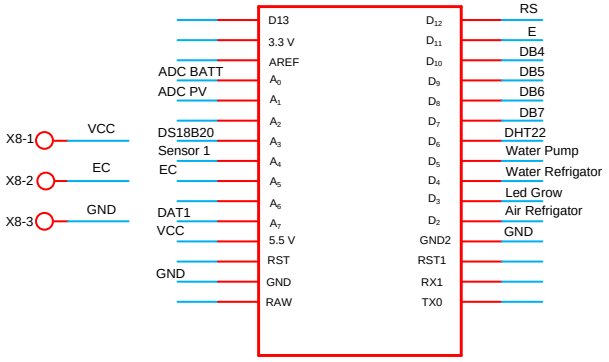


Figure 6. EC sensor circuit

G. *Sensor pH*

The pH sensor is an instrument for measuring the concentration of hydrogen in a solution. The pH sensors for water and for soil need to be calibrated periodically so that the accuracy of the measurement is guaranteed. The series of pH sensors installed in the greenhouse hydroponic system is connected to the Arduino-Uno, using the IDE software and libraries in the Arduino Uno. The pH sensor circuit is shown in Figure 7.

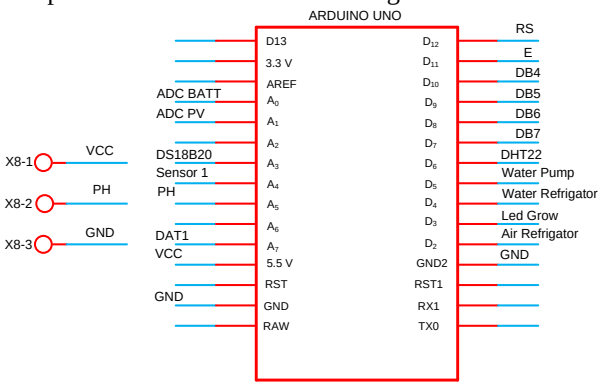


Figure 7. The pH sensor circuit

H. *Liquid Crystal Display*

Liquid Crystal Display (LCD) is a type of display media that uses liquid crystals as the main display. LCD has been used in various fields, for example in electronic devices, such as televisions, calculators, or computer screens. The LCD circuit that is installed with a greenhouse hydroponic is connected to the Arduino-Uno, using the IDE software and libraries in the Arduino Uno. Figure 8 shows the LCD circuit.

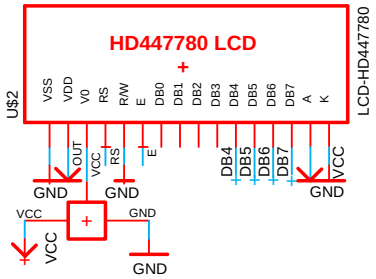
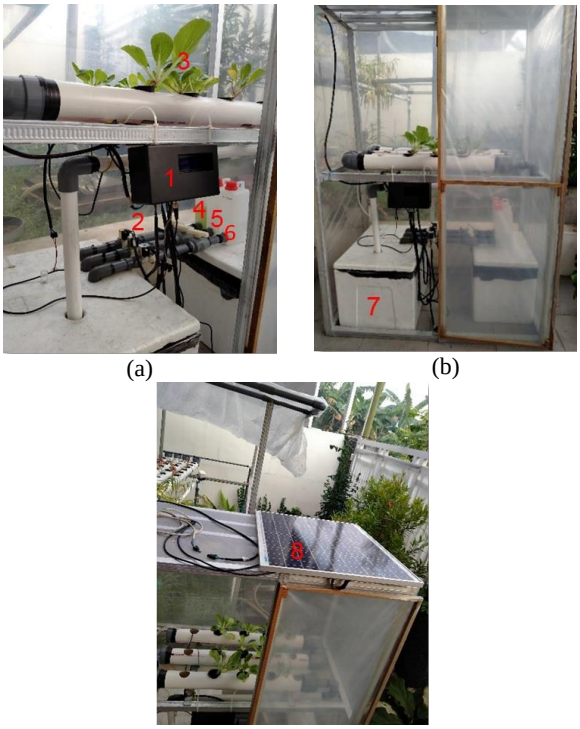


Figure 8. LCD circuit

III. Results and Discussion

Figure 9 shows the implementation of a monitoring system for pH and plant nutrition in a greenhouse hydroponic system using Arduino Uno. Figure 9.a shows (1) Arduino-Uno Controller, (2) Solenoid Valve, (3) Hydroponic Plant, (4) Nutrition EC, (5) pH-up, and (6) pH-down. Figure 9.b. shows nutrient water and sensors. Figure 9.c shows the PV module connected to a battery (Lithium-Ion). The working mechanism of this prototype is started by the sensors read the output voltage of the PV module. If the battery voltage is less than 12 V, the PV output power will charge the battery. In this condition, the battery voltage sensor will work and the water pump will also work. After the water pump starts then the EC sensor also works, with logic if the EC level is greater than 1 then the EC pump will turn on and if the EC level is less than 2 then the EC pump will shut down. Furthermore, the pH sensor works to monitor the PH level of the water. If the PH level is below 7 then the PH-down pump will work (On), otherwise if the pH level is above 7 then the pH-up pump will work (On). To obtain better monitoring and control system performance,

a number of validation measurements are carried out i.e. PV voltage, battery voltage, EC sensor, and pH sensor.



(a) (b)

(c)

Figure 9. Implementation of a monitoring system for pH and plant nutrition in a greenhouse hydroponic system

Table 1. Measurement of PV voltage

No.	Volt Meter (V)	PV Voltage Sensor (V)	Error (%)
1	5.00	5.07	1.400
2	7.00	7.10	1.429
3	9.00	9.09	1.000
4	12.00	12.08	0.667

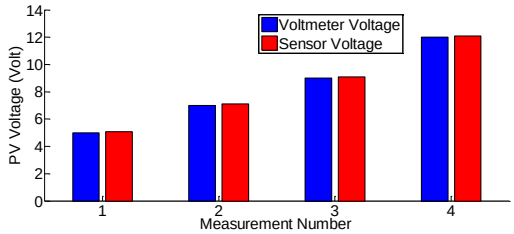


Figure 10. Measurement of PV voltage

Table 1 and Figure 10 show the PV voltage measurement using a voltmeter and a PV voltage sensor. The first measurement with a voltmeter produces a PV voltage of 5 V, while the measurement uses a sensor as 5.07 V. The fourth measurement with a voltmeter produces a PV voltage of 12 V, while the measurement uses a sensor as 12.08 V. The four measurement results show that the PV voltage sensor produces a measurement accuracy close to the same compared to measurements using a voltmeter with a maximum error of 1.429% or already below 5%.

Table 2 and Figure 11 show the battery voltage measurement using a voltmeter and a battery voltage sensor. The first measurement with a voltmeter produces a PV voltage of 5 V, while the measurement using a sensor resulting of 5.10 V. The fourth measurement with a voltmeter produces a PV voltage of 12 V, while the measurement using a sensor resulting of 12.07 V.

Table 2. Measurement of battery voltage

No.	Volt Meter (V)	Battery Voltage Sensor (V)	Error (%)
1	5.00	5.10	2.000
2	7.00	7.06	0.857
3	9.00	9.09	1.000
4	12.00	12.07	0.583

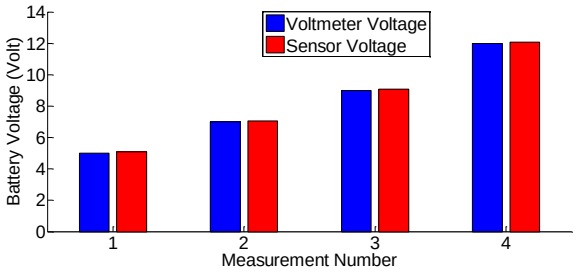


Figure 11. Measurement of battery voltage

The four measurements on Table 2 and Figure 11 show that the battery voltage sensor produces a measurement accuracy close to the same compared to measurements using a battery with a maximum error of 2% or already below 5%. PH sensor measurements are carried out to ensure the sensor can run properly because it can affect pH measurements when monitoring equipment is applied to hydroponic plants in greenhouse. Figure 12 shows pH measurements using a digital pH-meter. Figure 13 shows pH measurements using a pH sensor. Table 3 shows the measurements of water pH using a digital pH meter and pH sensor. Figure 13 shows the comparison of the pH of the water using a digital-meter and sensor.

Figure 12. pH measurement using digital-meter

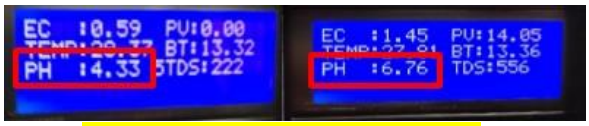


Figure 13. pH measurement using sensor

Table 3 Measurements of water pH using a digital pH meter and pH sensor

No.	PH Water	Digital PH meter	Error (%)	Sensor PH	Error (%)
1	4.00	4.0	0	4.33	8.250
2	6.86	6.8	0.875	6.76	1.458

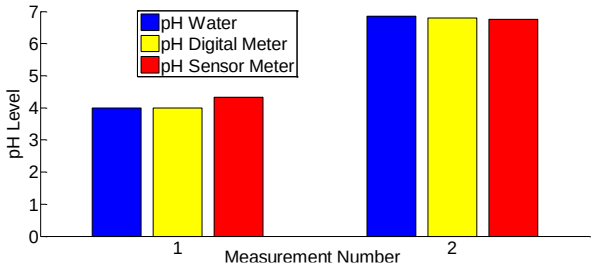


Figure 14. Comparison of the pH water using a digital-meter and sensor

Table 3 and Figure 14 show that on first measurement the pH value of water is 4, read by digital pH meter and pH sensor of 4.0 and 4.33, respectively. Otherwise, on the second measurement shows that the pH value of the water is 6.86, which is read by a digital pH meter and a pH sensor of 6.8 and 6.76, respectively. Table 3 shows that measurements using a digital pH meter and a pH sensor are able to give close to the same results. The measurement results of digital pH meter with water pH below 6 is accurate because they produce an error of 0%. Then, the measurement of pH digital meter with water pH values between 6-7 is relatively accurate because it produces an error of 0.875% or is already below 5%.

Table 3 and Figure 14 also show that on the first measurement results of pH sensors with water pH below 6 are still inaccurate because they produce an error of 8.250%. However, on the second measurement of pH sensors with water pH values between 6-7 is relatively accurate because it produces an error of 1.458% or is already below 5%. EC sensor measurements are carried out to ensure the nutrition sensor is functioning properly, because this indicator will affect the EC measurement of the water when the monitoring system is running. Table 4 shows the measurement of nutrition levels using the TDS sensor and the EC sensor.

Table 4. Nutrition measurement using TDS and EC sensors

No.	Digital TDS (ppm)	Sensor TDS (ppm)	Sensor EC (mS/cm)
1	450	458	1.23
2	540	542	1.45
3	760	765	2.05
4	880	882	2.30

The performance measurement of the pH monitoring system is carried out to ensure that the pH of the water can be controlled to a degree of acidity between 6-7. This range of values is needed to keep hydroponic plant growth relatively stable. The measurements are made on a hydroponic plant monitoring system, using a relay that functions to run the pH pump motor. The function of pH-Up and pH-Down is to keep the pH of hydroponic plant water at the level of 6-7. Table 5 shows the performance measurements of the pH sensor. Figure 15 shows the measurement of pH-Up performance at 08.00 and 14.00 hours.

Table 5. Performance measurement using pH sensor

Hours	Sensor pH	pH-Up	pH-Down
08.00	4.33	On	Off
10.00	6.45	Off	Off
12.00	6.76	Off	Off
14.00	7.32	Off	On
16.00	6.47	Off	Off

Figure 15. Performance measurement of pH-Up at 08.00 and 14.00 hours

Table 5 and Figure 15 show that at 08.00 the pH level is below 6 so that the pH-Up sensor is on. In this condition, the solenoid valve will open to drain pH-Up water so that the pH value rises to above 6. On the other hand, at 10.00, 12.00, 14.00, and 16.00 the pH level is above 6 so that the pH-Up sensor is in the Off status. Table 5 and Figure 15 also show that at 14.00 hours the pH level is above 7 so that the pH-down sensor is On. In this condition, the solenoid valve will open to drain pH-down water to lower the pH value to below 7. On the other hand, at 08.00, 10.00, 12.00, and 16.00 hours the pH level are already below 7 so that the pH-down sensor is automatically in the Off status.

The performance measurement of EC is carried out to ensure that the water nutrition concentration can be controlled within a value range of 1-2 mS/cm. The EC control is needed to keep hydroponic plant growth relatively stable. The measurements are made on the hydroponic plant monitoring system, using a relay that functions to run the EC pump motor. Table 6 shows the performance measurements using an EC sensor. Figure 15 shows the measurement of EC at 08.00 and 16.00 hours.

Table 6. Performance measurements using EC sensor

Hours	Sensor EC	EC-Up
08.00	0.59	On
10.00	1.45	Off
12.00	1.28	Off
14.00	1.32	Off
16.00	1.30	Off

Gambar 16. Performance measurement of EC sensor at 08.00 and 16.00 hours

Table 6 and Figure 16 show that at 08.00 hours the level of EC nutrition is still below 1 so that the EC-Up sensor is On. In this condition, the solenoid valve will open to drain EC water and raise the pH level to above 1. On the other hand, at 10.00, 12.00, 14,000, and 16.00 the EC nutrient level is already above 1 so that the EC-Up sensor is automatically in the Off status.

Table 7. Comparison between prototype hydroponic greenhouse-Arduino-Uno-standalone PV (proposed study) than previous studies

Authors	Methods/ Devices	Ph Level	EC Level	High/ Vol. Level	Temp. Level	Monitored by	Power Supply	Real Time	Green-house
Fitria Hidayanti, et.al. [1]	Arduino Uno	6-7	NA	18-20 cm	NA	LCD Display	Standalone PV-Battery	Yes	No
Helmy, et.al. [2]	Nutrient Film Technique	NA	1.4 mS or 700 ppm	NA	NA	Website	Grid PLN	No	No
Yuga Had-fridar Putra, et. al [3]	Microcontroller NodeMCU esp8266 v3	NA	600-800 ppm	5-10 cm	23^0-27^0 C	Website	Grid PLN	No	No
David Setiawan, et. al. [4]	Nutrient Film Technique	NA	NA	NA	NA	NA	Standalone PV-Battery	No	No
Muhammad Tirto Utomo, et.al [5]	Arduino Uno using Micro-controller ATMega16 U2	6-6.5	NA	6-8 cm	NA	LCD Display	Grid PLN	Yes	No
Muhammad Fakhruzzaini, et. al. [6]	Arduino Uno using Micro-controller ATMega328	5.5-7.5	NA	10-14 cm	NA	LCD 16 × 2 Display	Grid PLN	Yes	No
Ahmad Rifai, et.al. [7]	Arduino Uno using Fuzzy Logic Controller	NA	110-2000 µS/cm	10-100 mL	NA	LCD 16 × 2 Display	Grid PLN	Yes	No
Proposed Study	**Arduino Uno using Micro-controller ATMega328**	**6-7**	**1-2 mS/cm**	**NA**	**NA**	**LCD 20 × 4 Display**	**Standalone PV-Battery**	**Yes**	**Yes**

Note: NA = not available

Table 7 shows the prototype validation of the proposed hydroponic plant monitoring and control model compared to the previous seven prototypes. The parameters observed were pH level, EC level, high or volume water level, temperature level, measurement monitoring, hydroponic power supply, real-time measurement simulation, and the use of a greenhouse in a hydroponic system. In [1], Fitria Hidayanti, et. al have proposed Arduino Uno be supplied by Standalone PV-Battery to control the pH level and nutrient water level which their values monitored in real-time using an LCD. This prototype was able to control the pH level between 6-8 and the nutrition water level between 18-20 cm. In [2], Helmy, et. al. have proposed a Nutrient Film Technique supplied by the Indonesia Electric Company (PLN) grid to control the EC level of 1.4 ms or 700 ppm whose value was monitored wirelessly by the website. In [3], Yuga Hadfridar Putra, et.al have proposed the Arduino Uno be supplied by the PLN Grid to control the EC level, nutrition water high level, temperature, and its value to be monitored wirelessly by the website. This prototype was able to control the EC level between 600-800 ppm, a high level between 5-10 cm, and a temperature level of 23^0-27^0 C. The weakness of the prototype model in [2,3] was that it still used a database so that the measurement of performance parameters on both hydroponic systems still has a time delay. In [4], David Setiawan et.al have proposed Nutrient Film Technique to be supplied by Standalone PV-Battery. The weakness of this prototype only regulated the power supply from the PV-battery to the hydroponic system prototype and was still unable to control and monitor system performance parameters.

In [5], Muhammad Tirto Utomo, et. al proposed Arduino Uno using Microcontroller ATMega16 U2 be supplied by the PLN Grid to control the pH level, nutrient water level, and its value was able to be monitored in real-time using an LCD. This prototype was able to control the pH level between 6-6.5 and the nutrition water level between 6-8 cm. In [6], Muhammad Fakhruzzaini, et. al have proposed Arduino Uno using the ATMega328 Micro-controller supplied by the PLN grid to control the pH level between 5.5-6.5 and the nutrition water level

between 10-14 cm, and the value is monitored in real-time with a 16 × 2 LCD. In [7], Ahmad Rifai, et.al have proposed Arduino Uno using the Fuzzy Logic Controller supplied by the PLN Grid to control the EC level and nutrition water level and its value to be monitored real-time using a 16 × 2 LCD. This prototype was able to control EC levels between 110-2000 µS/cm and nutrition water volume between 10-100 mL. In this study, the authors propose Arduino Uno using a Microcontroller ATMega328 supplied by Standalone PV-Batteries to control pH and EC levels and monitor their values in real-time using a 20 × 4 LCD. This prototype was able to control pH levels between 6-7 and EC levels between 1-2 mS/cm. The advantage of the proposed model is that the character of the LCD is wider so that besides being able to display pH and EC parameter measurements, it is also able to display data on temperature, time, PV voltage, battery voltage, and TDS value. The proposed hydroponic system prototype also has been in the form of a greenhouse to keep the plant growth process taking place in the desired environmental conditions and at the same time preventing attacks from pests and diseases.

IV. CONCLUSION

The prototype model to monitor and control the pH levels and EC nutrition plant supplied by a standalone PV module-connected battery on greenhouse hydroponic systems has been implemented. The two sensors are connected to the Arduino Uno and relay control to drive four pumps, i.e. the water flow pump, EC pump, pH up pump, and pH down pump. The prototype model is able to monitor and control the pH of hydroponic plant water at the level between 6-7 using pH-up and pH-down sensor. This model is also able to monitor and control nutrition plant water over 1 mS/cm using EC sensor. The advantage of the proposed model is that the character of the 20 × 4 LCD is wider so that besides being able to display pH and EC parameter measurements, it is also able to display data on temperature, time, PV voltage, battery voltage, and TDS value. The proposed hydroponic prototype system also has been in the form of a greenhouse to keep the plant growth process taking place in the desired environmental conditions and at the same time preventing attacks from pests and diseases. The implementation of the EC sensor is only able to control the EC value if the value is less than 1 mS/cm. On the other hand, optimal plant growth in a hydroponic greenhouse system requires controlled EC values between 1-2 mS/cm. The use of an EC-down sensor to control the EC value so as not to exceed the 2 mS/cm value is proposed as future work to overcome this problem.

ACKNOWLEDGEMENT

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Lampiran 2.7

Rekap penjelasan revisi penulis terhadap review pertama dan kedua

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AUTHOR REVISION REPORT

Note: For comments/questions/Answer/Revisions, use the language according to the language used in the manuscript (English or Bahasa Indonesia).

I. Manuscript Identity

Title	Monitoring and Controlling of pH Levels and Plant Nutrition Supplied by Standalone Photovoltaic in a Greenhouse Hydroponic System using Arduino Uno
Manuscript number	45657
Article Type	Research article / ~~Review Article~~
First Submission date	2021-03-15
Recommendation on First Submission Manuscript	Reviewer 1 (RV1): **Accepted with Minor Revisions** Reviewer 2 (RV2): **Accepted with Minor Revisions**.
Revision Submission Date	**11 April 2021**

II. Reviewer's Comments

2.1. General Impression

	Reviewers (R1 & R2) Comments/Questions	Authors Comments/Answers/Revisions in the Manuscript
General comprehension of the manuscript	**Comments** [R1] This paper presents an approach to monitor and control pH levels (6-7) and plant nutrition supplied. [R2] Makalah ini membahas tentang pengendalian pH dan nutrisi pada tanaman hidroponik, hanya untuk judul terlalu Panjang akan lebih bagus dapat disingkat.	**Answers** [R1] Thanks a lot for your valuable comment. [R2] Makalah dalam bentuk kalimat pasif dan menurut penulis sudah cukup proporsional serta tidak terlalu panjang untuk menjelaskan substansi makalah.
Language/style/ Grammar in general	[R1] It is good; however, it is required to be improved to increase the readability. [R2] Baik, hanya masih terdapat kalimat salah ketik	[R1] Thanks a lot for your valuable comment. This paper has been revised to increase readability. [R2] Kalimat salah ketik pada makalah ini sudah diperbaiki oleh penulis.
Structure	[R1] Good and understandable. It has followed ELKHA's template. [R2] Baik	[R1] Thanks a lot for your valuable comment. [R2] Terima-kasih atas komentar positif reviewer.
Level of enthusiasm	[R1] Medium. In the implementation, the paper sounds nice to read. The novelty needs to be explained explicitly to give a confidence to the readers that this paper coveys a new approach or idea on controlling pH dan nutrition supplied. [R2] Baik.	[R1] Thanks a lot for your valuable comment. This paper has been revised to show novelty. It has been explained explicitly to give a confidence to the readers that this paper coveys a new approach or idea on controlling pH and nutrition supplied as well as fully described in Table 7. [R2] Terima-kasih atas komentar positif reviewer.

2.2. Revision on Major Comments

	Reviewers (R1 & R2) Major Comments	Authors Answers/Revisions in the Manuscript
Abstract	[R1.1] The Abstract has been summarizing the paper including the key results. [R1.2] The grammar of some sentences, required to be improved to increase the readability. For instance, *"The Arduino Uno circuit with a 20 × 4 liquid crystal display (LCD) order four relays to monitor and control the four pumps of greenhouse hydroponic system based on the coding which has been programmed previously.",* somehow can misinterpreted, the word "order" should be replaced with other word, depending on its true meaning. Check other sentences too, to make sure it contains readability sentence and no unnecessary information. [R2.1]. Sudah terdapat abstrak, hanya perlu perbaikan pada kalimat yang sama dengan kesimpulan.	[R1.1] Thanks a lot for your valuable comment. [R1.2] Abstract has revised base on your comments. Please see in the abstract section on Page 1 (The revised sentences are marked in yellow shadows). [R2.1] Abstrak sudah diperbaiki supaya tidak sama dengan kalimat di kesimpulan. Mohon dilihat di bagian abstrak halaman 1 kolom 1 (Kalimat revisi ditandai oleh bayangan kuning).
Introduction	[R.1.3] The explanation is well organized and effective, however need to be clearer. The author only gives the drawback on approach in [4], the authorshould also explain the drawback approaches in [1]-[3], to increase confidence of the readers, that the proposed approach gives a level of novelty. [R.1.4] Add more citations in this section, it will increase the quality of the paper. [R.1.5] The last paragraph has already try to explain what is proposed in this paper, but it is better not the technical, but the concept which is novel and different with the previous approach. The technical terms can be added, but the details should be written in methodology and results and discussion section. [R.2.2] Terdapat penjelasan yang kurang (lihat lampiran)	[R.1.3] The authors have explained the drawback approaches in [1]-[3], to increase the confidence of the readers, that the proposed approach gives a level of novelty. Please see in Introduction Section (Sec.1) on Page 1 (Column 1 and 2) and on Page 2 (Column 1 and Paragraph 1) (The revised sentences are marked in yellow shadows). [R.1.4] The authors have added three new citations and their analysis in Sec. 1 (Ref. 5, 6, and 7) to increase the quality of the paper. Please see in Introduction Section (Sec.1) on Page 2 (Column 1 and Paragraph 2) (The revised sentences are marked in yellow shadows). [R.1.5]. The novelty of this paper has been mentioned in Sec 1 but not technical analysis. You can see in detail in Table 7 and both the last paragraph in Result and Discussion (Sec. 3-Page 7-8) and Conclusion (Sec 4-Page 8). (The revised sentences are marked in yellow shadows). [R.2.2] Penjelasan yang kurang di lampiran sudah direvisi semua oleh penulis. (Kalimat revisi ditandai oleh bayangan kuning).
Methodology	[R.1.6] Overall, the methodology is particularly good and easy to follow. It is better there one sentence or more saying ''as a statement' what the new method proposed which is different with previous approaches. This will increase citation to your paper once it is published.	[R.1.6] The authors have added one sentence of the new method proposed which is different from previous approaches. (Figure 1 shows the proposed research model. This proposed model is called the monitoring system for pH and plant nutrition in a greenhouse hydroponic system using Arduino Uno…..). Please see

		revision in Sec. 2-Page 3-Column 1-Paragraph 1. (The added sentences are marked in yellow shadows).
	[R.2.3] Pada Flowchart perlu dicek kembali, ada pembahasan yang tidak nyambung dengan judul.	[R.2.3] Flowchart pada Gambar 2 dan analisisnya sudah direvisi sesuai dengan saran reviewer. Mohon dilihat pada Gambar 2 dan penjelasannya di halaman 3, kolom 1, dan bagian akhir paragraph 1 (Kalimat revisi ditandai oleh bayangan kuning).
Results and Discussions	[R.1.7] The results documentation is quite convincing in terms of implementation. [R.1.8] I think there are some typos in Section III praragraph 1, in the second tillfourth sentence. Instead Figure 7.a, 7.b., and 7.c., It should be Figure 9a, 9b, dan 9c. [R.1.9] The first sentence in the second paragraph, I think it should be Figure 10the Figure number also should be 10, since there are two Figure 9. [R.1.10] The standard error or error tolerance required for the system must be mentioned for each measurement, shown in the tables and their explanation. [R.1.11] For easy to read, there should be space between figures, tables, and sentences.	[R1.7] Thanks a lot for your valuable comment. [R1.8] The authors have revised Figure 7.a, 7.b., and 7.c. to be Figure 9a, 9b, and 9c. Please see revision in Sec. 3-Page 4-Column 2-Paragraph 1. (The revisions are marked in yellow shadows). [R.1.9] The authors have revised the first sentence in the second paragraph as Figure 10 and also its figure number. [R.1.10] The standard error of measurement has been mentioned and analyzed in Table 1, Table 2, and Table 3. [R.1.11] The authors have added space between all figures, tables, and sentences.
	[R.2.4] Cek kembali penomoran gambar.	[R.2.4] Penomoran Gambar 1 s/d Gambar 16 sudah direvisi dan diurutkan.
Conclusions	[R.1.12] The conclusion is good. One thing to be added is what is the key results,and is it solve the problem or better than the previous approach. This statement is important to give a level of confidence for the readers to cite the paper.	[R.1.12] The authors have added the key results of this research to the previous research. Please see the key points in Sec. 4-Page 8-Column 1. (The revision sentences are marked in yellow shadows).
	[R.2.5] Kalimat copy paste dari abstrak-untuk di cek kembali	[R.2.5] Kalimat copy paste dari abstrak-di kesimpulan sudah direvisi. Mohon dilihat pada Bab 4, Hal. 8, dan Kolom 1 (Revisi ditandai dengan tulisan bayangan kuning).

2.3. Revision on Minor Comments

	Reviewers (R1 & R2)	**Authors**
	Minor Comments/Questions	**Comments/Answers/Revisions in the Manuscript**
Style/Grammar	[R1.1] Good, Improve the presentation of your paper (style/grammar) with the help of the language tools or other person that has a very good English capability, since once your paper published, it will be read by the people in the world. Therefore, the good presentation can make them to have a will to read the paper, or	[R1.1] Thanks a lot for your valuable comments.

	even cite it and collaborate with the author.	
Consistency/Terminology	[R1.2] Good	[R1.2] Thanks a lot for your valuable comments.
References	[R1.3] Follow the template. Some list has a shadow background, check it.	[R1.3] The authors have followed all templates of the ELKHA manuscript.
Tables	[R1.4] Some tables has no space or even has big space with the Figure or sentence close to it, Give an appropriate space between them. [R.2.1]Format tabel cek kembali, sesuaikan dengan template jurnal ELKHA	[R1.4] The authors have revised and given an appropriate space between all tables, figures, and sentences in this manuscript. [R.2.1] Saya sudah merevisi format penulisan tabel sesuai template makalah ELKHA.
Figures	[R.1.5]. There are two Figure 9 in Section III. [R.1.6]. Some figures has no space or even has big space with the Figure or sentence close to it, Give an appropriate space between them. [R.2.7] Terdapat gambar yang kurang jelas, kabur.	[R.1.5]. The authors have revised both figures into Fig. 9 and Fig. 10. Please see on Page 5-Column 1. (The revision are marked in yellow shadows). [R.1.6]. The authors have revised and given an appropriate space between all tables, figures, and sentences in this manuscript. [R.2.7] Gambar 5 dan Gambar 8 yang kabur sudah digambar ulang supaya lebih jelas.

Lampiran 2.8

Surat pernyataan penulis

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Judul Naskah : Monitoring and Controlling of Ph Levels and Plant Nutrition Supplied by Standalone Photo-Voltaic in Greenhouse Hydroponic System Using Arduino Uno
Penulis : 1. LUTFI ATHANUZUL KURNIAWAN
2. AMIRULLAH
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Monitoring and Controlling of pH Levels and Plant Nutrition Supplied by Standalone Photovoltaic in a Greenhouse Hydroponic System using Arduino Uno

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***Abstract* – This paper aims to implement the prototype model to monitor and control the pH levels and nutrition plant (electrical conductivity-EC) supplied by a standalone photovoltaic (PV) module-connected battery (Lithium-Ion) on the greenhouse hydroponic systems. The pH and EC sensors are connected to the Arduino Uno circuit as a relay control to drive four pumps, i.e. the water flow pump, EC pump, pH up pump, and pH down pump. The greenhouse function to control pests and the impact of environmental non-uniformity caused by variation of wind speed, temperature, or sunlight so that hydroponic plants can grow in an appropriate environment. The Arduino Uno circuit with a 20 × 4 liquid crystal display (LCD) order four relays to monitor and control the four pumps of the greenhouse hydroponic system based on the coding which has been programmed previously. The prototype model is able to monitor and control the pH of hydroponic plant water at the level between 6-7 using a pH-up and pH-down sensor. This model is also able to monitor and control nutrition plant water over 1 mS/cm using an EC sensor. Finally, the proposed prototype is able to monitor and control EC and pH level to regulate plant growth in the greenhouse hydroponic system normally and in real-time.**

Keywords: Standalone PV, pH, EC, Greenhouse, Hydroponic, Arduino Uno

I. INTRODUCTION

Recently, hydroponics has become a new method of cultivating plants, especially various types of vegetables or fruit, because they do not require large areas of land and can be done in the yard of the house. The hydroponic method uses a solution of mineral nutrients and water without using soil media for the process of growing and maintaining plants. Hydroponic cultivation in greenhouses is now an option to overcome the constraints of cultivating plants in open areas i.e. attack by pests, wind, temperature, and sunlight which sometimes also interfere with the growth and development of vegetable or fruit plants.

The PV module is a source of electrical power to operate the pH control system and the water level of hydroponic plant nutrients until the harvest period has been implemented in [1]. The proposed prototype was able to control the water pH level of 6-7 and the nutrition solution height of 18-20 cm. This model works when the pH sensor detects below 6 then the solenoid valve at pH-up automatically opens and flows into the nutrition solution. Thus, when the sensor detects a pH of more than 7, the solenoid valve will open and the pH-down solution will flow into the nutrition solution. The solenoid valve will close again when the sensor detects the pH in the range of 6-7. The water level control works when the ultrasonic sensor detects a value of 18 cm, the solenoid valve will open and the nutrition water flows into the nutrition bath, otherwise, the solenoid valve closes again when the sensor detects a value of 20 cm. However, this prototype did not use an EC sensor to detect the level of the nutrition solution in the water. The pH control and nutrient levels are regulated by a solenoid valve, actuated by a water pump, and the power is supplied by the PV module for 24 hours with varying tilt angles.

The EC wireless sensor supplied by Indonesia Electric Company (PLN) grid to monitor and control the concentration of the nutrient solution for hydroponic plant cultivation using two Nutrient Film Technique (NFT) tables based has been proposed in [2]. Each table was installed with monitoring and controlling of nutrition solution concentration devices which transmit the data to server through wireless sensor network. The results showed that the EC-meter sensor was able to read the density of the nutrient solution with a relative error percentage of 3.92%. Node 2 was able to produce a faster threshold data transmission than node 1 with a delay for node 2 of 34.68 seconds and a delay for node 1 of 40.01 seconds. Node 1 was able to result in a better control accuracy of nutrient solution concentration at 96.12% compared to node 2 at 92.79%. The weakness of this model was the performance of monitoring and control depending on temperature and the distance between the node and the coordinator. The higher the system temperature, so its performance also decreases. The farther the distance between the node and the coordinator, the loss of data transmission also will be greater.

The nutritional control, water temperature, water volume, environmental temperature, pH, and humidity on the hydroponic system using the website has been implemented in [3]. The control of this prototype used the Node MCU esp 8266 v3 microcontroller. Data communication between hardware and software used wireless media. Temperature reading system water using the DS18B20 sensor, the water level using the HC-SR04 ultrasonic sensor, and the nutrition level measured by the nutrition solution sensor. This device was designed to be

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able to monitor and control the hydroponic system at nutrient temperatures at 23°C-27°C, water height limits 5-10 cm and nutrient levels at the 600-800 ppm limit. The weakness of this research was that it still operates using the website browser menu so that it requires internet access to monitor and control all parameters through this prototype model. The design of PV modules as a power source for DC pump and compared by AC pump to control water flow that supplies nutrients to NFT-type hydroponic plants has been proposed in [4]. This model showed that the use of solar panels and DC pumps to flow water to hydroponic plants is relatively more economical than an AC pump. However, the DC pump was not able to operate continuously, and to overcome this problem then the researchers proposed an AC pump using a DC-AC inverter to drain water in the hydroponic system.

Control of pH and nutrition water levels in the hydroponic system of chili plants using Arduino Uno with microcontroller ATmega16 U2 has been observed in [5]. This prototype was capable of controlling a pH level between 6-6.5 and a nutrition water level between 6-8 cm. The prototype of measuring and controlling water volume and water pH levels in hydroponic system using ultrasonic sensor and pH sensor with Arduino Uno have been proposed in [6]. The proposed system was capable of controlling water level between 10-14 cm and water pH between 5.5-7.5. The prototype of the EC control and water volume on hydroponic system using fuzzy logic has been observed in [7]. Fuzzy logic control using the EC sensor was able to control EC between 110-2000 µS/cm and generate good performance with an average error of 1.91%. This model was also able to control the volume of water between 10-100 mL with an average error of 1.87%. Nevertheless, the drawback of prototype model in [2,3,5,6,7] was completely dependent on grid electricity so that if there is a supply disruption at the source side, the control and monitoring of hydroponic system will not be able to function normally.

This research will implement the prototype model to monitor and control the pH levels and nutrition plant supplied by a 100 watt-peak (Wp) standalone PV panel-connected battery on greenhouse hydroponic systems. The two sensors are connected to the Arduino Uno circuit as a relay control to drive four pumps, i.e. the water flow pump, EC pump, pH up pump, and pH down pump. The greenhouse function to control pests and environmental temperatures so that hydroponic plants can grow in an appropriate environment. The paper is arranged as follows. Chapter II presents the proposed research model, flow chart, PV module concept, greenhouse, Arduino Uno, relay circuit, pH sensor, EC sensor, liquid crystal display (LCD). Chapter III presents the results and discussion i.e. the design of monitoring and control systems for pH and EC levels, measurement and validating the PV and battery module voltages, measurement and validating pH sensor, measurement and validating EC sensor as well as analyzing the performance measurement result of pH sensor and EC sensor in greenhouse hydroponic plant systems. Finally, the paper is concluded in Chapter IV.

II. METHODOLOGY

A. *Research Method*

The monitoring and control system for pH and EC nutrition in the hydroponic greenhouse prototype consists of a combination of hardware and software. The hardware design consists of a PV module, battery (Lithium-Ion), pH sensor, and EC nutrition sensor combined with Arduino Uno software connected to four relays. These relays function to control the water flow pump, nutrient pump (EC), pH-up pump, and pH-down pump. The block diagram of the proposed model can be seen in Figure 1.

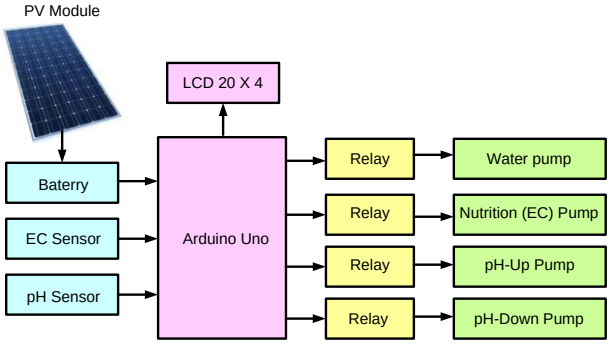


Figure 1. Proposed research model

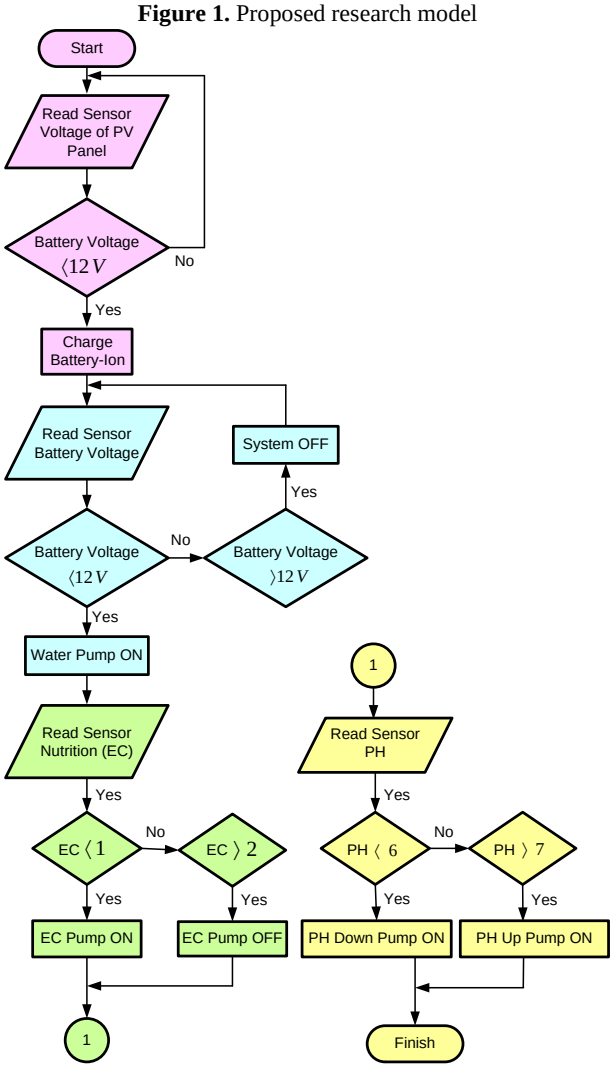


Figure 2. Research flowchart

Figure 1 shows the proposed research model. This proposed model is called the monitoring system for pH and plant nutrition in a greenhouse hydroponic system using Arduino Uno. The 100 Wp standalone photovoltaic (PV) module charges the battery (Lithium-Ion). After the battery is fully charged, the EC sensor and PH sensor will work. The Arduino Uno circuit with a 20 × 4 LCD display will then order four relays i.e. water flow pump, nutrient (EC) pump, pH-up pump, and pH-down pump to work to control the hydroponic system in a greenhouse based on the coding which has been written previously on Arduino-Uno. Figure 2 shows the research flowchart. The research starts with the sensor reading the PV module output voltage. If the battery voltage is less than 12 V, the PV power will charge previously the battery. Then, the battery voltage sensor will work logically if the battery voltage is less than 12 V, then the water flow pump will work. Whereas if the battery voltage exceeds 12 V, the system will shut down. After the water pump starts, the nutrition sensor (EC) will work logically if the EC is less than 1 then the EC pump will turn On and if the EC is greater than 2 then the EC pump will turn Off. Furthermore, the pH sensor works to monitor the pH level of the water. If the pH level is below 7 then the PH pump down will work (On), conversely if the pH level is above 7 then the pH up pump will work (On).

B. Modelling Photovoltaic

The equivalent circuit of PV is shown in Figure 3. It consists of several PV cells which have external connections in series, parallel, or series-parallel [5].

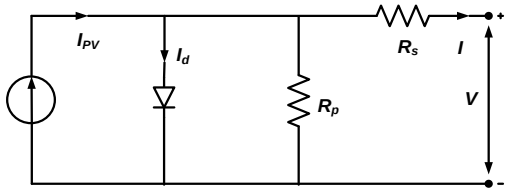


Figure 3. Equivalent circuit of PV panel

The V-I characteristic is shown in Eq. (1):

$$I = I_{PV} - I_o \left[exp\left(\frac{V+R_S I}{a\,V_t}\right) - 1 \right] - \frac{V+R_S I}{R_P} \quad (1)$$

Where I_{PV} is PV current, I_o is saturated re-serve current, 'a' is the ideal diode constant, $V = N_S KTq^{-1}$ is the thermal voltage, N_S is a number of series cells, q is the electron charge, K is Boltzmann constant, T is temperature pn junction, R_S and R_P are series and parallel resistance of solar panels. I_{PV} has a linear relationship with light intensity and also temperature variation. I_o is a dependent value on the temperature variation. Eq. (2) and Eq. (3) are the calculation of I_{PV} and I_o values:

$$I_{PV} = \left(I_{PV,n} + K_I \Delta T\right)\frac{G}{G_n} \quad (2)$$

$$I_o = \frac{I_{SC,n} + K_I \Delta T}{exp\,(V_{OC,n} + K_V \Delta T)/aV_t - 1} \quad (3)$$

Where, $I_{PV,n}$, $I_{SC,n}$, and $V_{OC,n}$ are the photovoltaic current, short circuit current, and open-circuit voltage under standard conditions ($T_n = 25^0 C$ and $G_n = 1000\,W/m^2$), respectively. The K_I value is the coefficient of short circuit current to temperature, $\Delta T = T - T_n$ is temperature deviation from standard temperature, G is the light intensity and K_V is coefficient of open-circuit voltage ratio to temperature. Open circuit voltage, short circuit current, and voltage-current related to maximum power are three important values of I-V characteristics of PV panel. These points are changed by variation in atmospheric conditions. By using Eq. (4) and Eq. (5) derived from the PV model equation, short-circuit current and open-circuit voltage can be calculated under different atmospheric conditions.

$$I_{SC} = (I_{SC} + K_I \Delta T)\frac{G}{G_n} \quad (4)$$

$$V_{OC} = (V_{OC} + K_V \Delta T) \quad (5)$$

C. Green House

The greenhouse is a frame or corrugated building covered with a clear or translucent material that can transmit light optimally for production and protect plants from climatic conditions that are detrimental to plant growth. The cultivating of plants in a greenhouse has the advantage of a more controlled microenvironment and uniformity of production for each plant. The functions of a greenhouse include managing plant growth schedules, increasing production yields, minimizing pesticides, increasing production quality, assets, and performance, as well as a means of agro-tourism [6].

D. Arduino Uno

Arduino-Uno is an electronic board containing an ATMega328 microcontroller, which is a chip that functionally acts like a computer. This device is used to realize electronic circuits from simple to complex. LED control to robot control can be implemented using this relatively small board. In the health sector with the addition of certain components, this tool can be used to monitor the condition of patients in the hospital and control equipment at home [7]. Figure 4 shows the Arduino Uno model.

Figure 4. Arduino Uno model

E. Relay Circuit

The relay circuit is a link between the Arduino Uno circuit with the water flow pump, nutrient pump (EC), pH-up pump, and pH-down pump to work on controlling the greenhouse hydroponic system based on the coding previously programmed on Arduino-Nano. Figure 5 shows a relay circuit on the greenhouse hydroponic system.

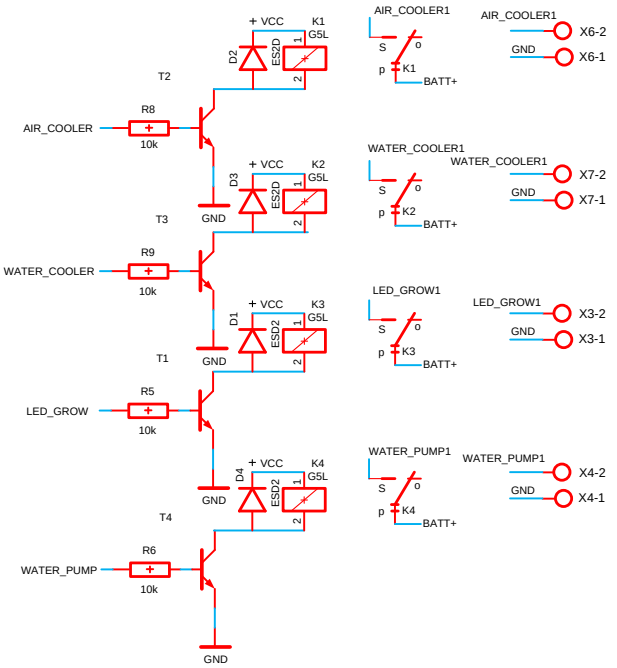


Figure 5. Relay circuit

F. Sensor Electrical Conductivity

The Electrical Conductivity (EC) sensor is used to measure the concentration of a solution for example hydroponic nutrient solution which is expressed in units of miliSiemens per centimeter (mS/cm). The EC-meter is an alternative measurement device to the Total Dissolved Solids (TDS)-meter to measure the concentration of a hydroponic nutrient solution expressed in units of parts per million (ppm) [8]. The EC value affects the rate of nutrition absorption by plants, the greater the EC value, the faster the absorption of nutrition by plants and vice versa if the EC value is smaller, the absorption of nutrition will be slow [9]. The series of EC sensors installed in the greenhouse hydroponic system is connected to the Arduino-Uno, using the IDE software and libraries in the Arduino Uno. Figure 6 shows the EC sensor circuit.

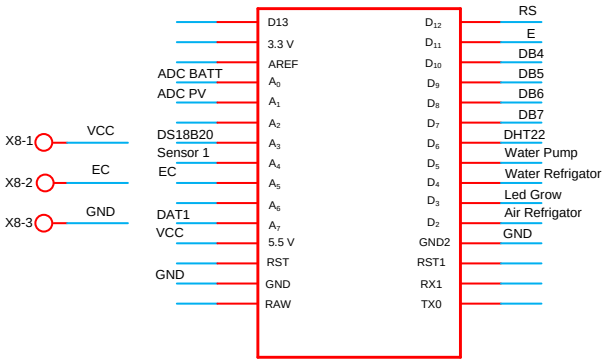


Figure 6. EC sensor circuit

G. Sensor pH

The pH sensor is an instrument for measuring the concentration of hydrogen in a solution. The pH sensors for water and for soil need to be calibrated periodically so that the accuracy of the measurement is guaranteed. The series of pH sensors installed in the greenhouse hydroponic system is connected to the Arduino-Uno, using the IDE software and libraries in the Arduino Uno. The pH sensor circuit is shown in Figure 7.

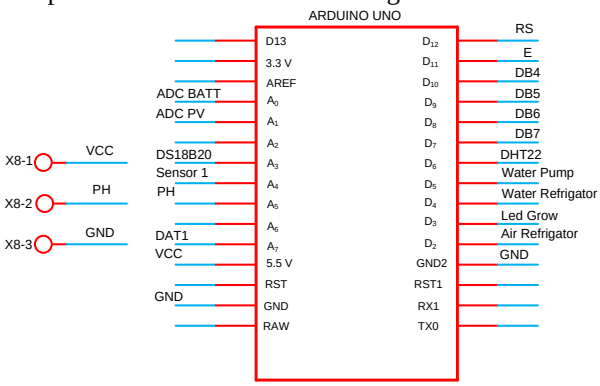


Figure 7. The pH sensor circuit

H. Liquid Crystal Display

Liquid Crystal Display (LCD) is a type of display media that uses liquid crystals as the main display. LCD has been used in various fields, for example in electronic devices, such as televisions, calculators, or computer screens. The LCD circuit that is installed with a greenhouse hydroponic is connected to the Arduino-Uno, using the IDE software and libraries in the Arduino Uno. Figure 8 shows the LCD circuit.

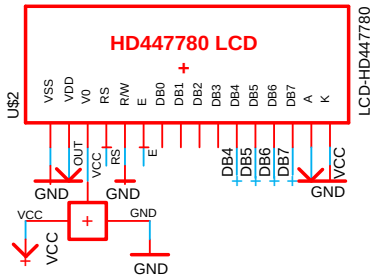
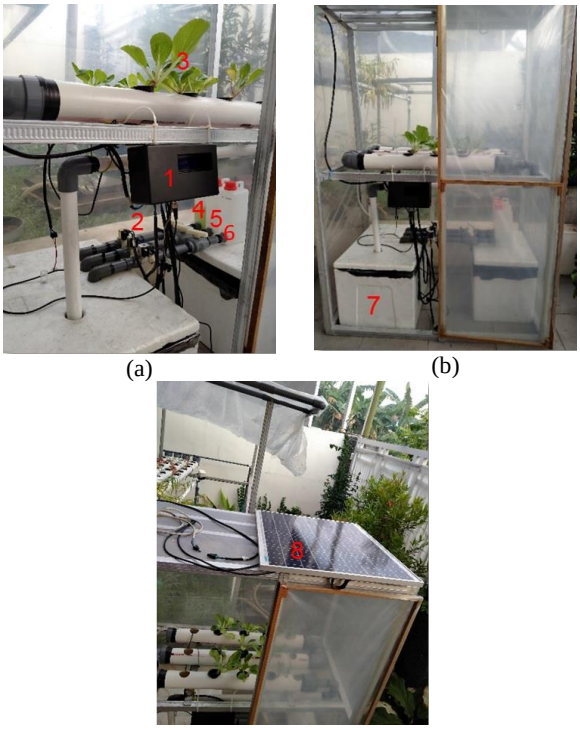


Figure 8. LCD circuit

III. Results and Discussion

Figure 9 shows the implementation of a monitoring system for pH and plant nutrition in a greenhouse hydroponic system using Arduino Uno. Figure 9.a shows (1) Arduino-Uno Controller, (2) Solenoid Valve, (3) Hydroponic Plant, (4) Nutrition EC, (5) pH-up, and (6) pH-down. Figure 9.b. shows nutrient water and sensors. Figure 9.c shows the PV module connected to a battery (Lithium-Ion). The working mechanism of this prototype is started by the sensors read the output voltage of the PV module. If the battery voltage is less than 12 V, the PV output power will charge the battery. In this condition, the battery voltage sensor will work and the water pump will also work. After the water pump starts then the EC sensor also works, with logic if the EC level is greater than 1 then the EC pump will turn on and if the EC level is less than 2 then the EC pump will shut down. Furthermore, the pH sensor works to monitor the PH level of the water. If the PH level is below 7 then the PH-down pump will work (On), otherwise if the pH level is above 7 then the pH-up pump will work (On). To obtain better monitoring and control system performance, a number of validation

measurements are carried out i.e. PV voltage, battery voltage, EC sensor, and pH sensor.



(a) (b)

(c)

Figure 9. Implementation of a monitoring system for pH and plant nutrition in a greenhouse hydroponic system

Table 1. Measurement of PV voltage

No.	Volt Meter (V)	PV Voltage Sensor (V)	Error (%)
1	5.00	5.07	1.400
2	7.00	7.10	1.429
3	9.00	9.09	1.000
4	12.00	12.08	0.667

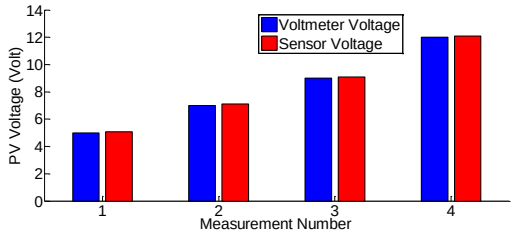


Figure 10. Measurement of PV voltage

Table 1 and Figure 10 show the PV voltage measurement using a voltmeter and a PV voltage sensor. The first measurement with a voltmeter produces a PV voltage of 5 V, while the measurement uses a sensor as 5.07 V. The fourth measurement with a voltmeter produces a PV voltage of 12 V, while the measurement uses a sensor as 12.08 V. The four measurement results show that the PV voltage sensor produces a measurement accuracy close to the same compared to measurements using a voltmeter with a maximum error of 1.429% or already below 5%.

Table 2 and Figure 11 show the battery voltage measurement using a voltmeter and a battery voltage sensor. The first measurement with a voltmeter produces a PV voltage of 5 V, while the measurement using a sensor resulting of 5.10 V. The fourth measurement with a voltmeter produces a PV voltage of 12 V, while the measurement using a sensor resulting of 12.07 V.

Table 2. Measurement of battery voltage

No.	Volt Meter (V)	Battery Voltage Sensor (V)	Error (%)
1	5.00	5.10	2.000
2	7.00	7.06	0.857
3	9.00	9.09	1.000
4	12.00	12.07	0.583

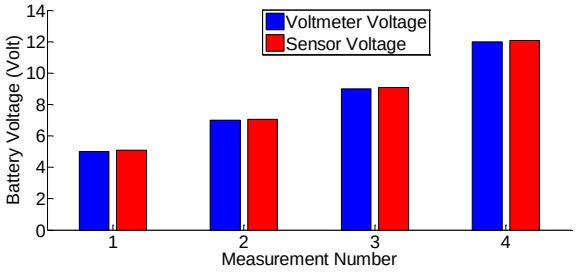


Figure 11. Measurement of battery voltage

The four measurements on Table 2 and Figure 11 show that the battery voltage sensor produces a measurement accuracy close to the same compared to measurements using a battery with a maximum error of 2% or already below 5%. PH sensor measurements are carried out to ensure the sensor can run properly because it can affect pH measurements when monitoring equipment is applied to hydroponic plants in greenhouse. Figure 12 shows pH measurements using a digital pH-meter. Figure 13 shows pH measurements using a pH sensor. Table 3 shows the measurements of water pH using a digital pH meter and pH sensor. Figure 13 shows the comparison of the pH of the water using a digital-meter and sensor.

Figure 12. pH measurement using digital-meter

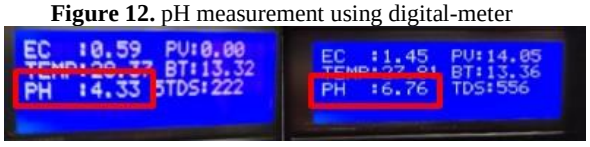


Figure 13. pH measurement using sensor

Table 3 Measurements of water pH using a digital pH meter and pH sensor

No.	PH Water	Digital PH meter	Error (%)	Sensor PH	Error (%)
1	4.00	4.0	0	4.33	8.250
2	6.86	6.8	0.875	6.76	1.458

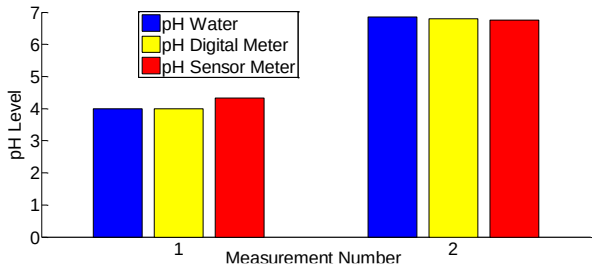


Figure 14. Comparison of the pH water using a digital-meter and sensor

Table 3 and Figure 14 show that on first measurement the pH value of water is 4, read by digital pH meter and pH sensor of 4.0 and 4.33, respectively. Otherwise, on the second measurement shows that the pH value of the water is 6.86, which is read by a digital pH meter and a pH sensor of 6.8 and 6.76, respectively. Table 3 shows that measurements using a digital pH meter and a pH sensor are able to give close to the same results. The measurement results of digital pH meter with water pH below 6 is accurate because they produce an error of 0%. Then, the measurement of pH digital meter with water pH values between 6-7 is relatively accurate because it produces an error of 0.875% or is already below 5%.

Table 3 and Figure 14 also show that on the first measurement results of pH sensors with water pH below 6 are still inaccurate because they produce an error of 8.250%. However, on the second measurement of pH sensors with water pH values between 6-7 is relatively accurate because it produces an error of 1.458% or is already below 5%. EC sensor measurements are carried out to ensure the nutrition sensor is functioning properly, because this indicator will affect the EC measurement of the water when the monitoring system is running. Table 4 shows the measurement of nutrition levels using the TDS sensor and the EC sensor.

Table 4. Nutrition measurement using TDS and EC sensors

No.	Digital TDS (ppm)	Sensor TDS (ppm)	Sensor EC (mS/cm)
1	450	458	1.23
2	540	542	1.45
3	760	765	2.05
4	880	882	2.30

The performance measurement of the pH monitoring system is carried out to ensure that the pH of the water can be controlled to a degree of acidity between 6-7. This range of values is needed to keep hydroponic plant growth relatively stable. The measurements are made on a hydroponic plant monitoring system, using a relay that functions to run the pH pump motor. The function of pH-Up and pH-Down is to keep the pH of hydroponic plant water at the level of 6-7. Table 5 shows the performance measurements of the pH sensor. Figure 15 shows the measurement of pH-Up performance at 08.00 and 14.00 hours.

Table 5. Performance measurement using pH sensor

Hours	Sensor pH	pH-Up	pH-Down
08.00	4.33	On	Off
10.00	6.45	Off	Off
12.00	6.76	Off	Off
14.00	7.32	Off	On
16.00	6.47	Off	Off

Figure 15. Performance measurement of pH-Up at 08.00 and 14.00 hours

Table 5 and Figure 15 show that at 08.00 the pH level is below 6 so that the pH-Up sensor is on. In this condition, the solenoid valve will open to drain pH-Up water so that the pH value rises to above 6. On the other hand, at 10.00, 12.00, 14.00, and 16.00 the pH level is above 6 so that the pH-Up sensor is in the Off status. Table 5 and Figure 15 also show that at 14.00 hours the pH level is above 7 so that the pH-down sensor is On. In this condition, the solenoid valve will open to drain pH-down water to lower the pH value to below 7. On the other hand, at 08.00, 10.00, 12.00, and 16.00 hours the pH level are already below 7 so that the pH-down sensor is automatically in the Off status.

The performance measurement of EC is carried out to ensure that the water nutrition concentration can be controlled within a value range of 1-2 mS/cm. The EC control is needed to keep hydroponic plant growth relatively stable. The measurements are made on the hydroponic plant monitoring system, using a relay that functions to run the EC pump motor. Table 6 shows the performance measurements using an EC sensor. Figure 15 shows the measurement of EC at 08.00 and 16.00 hours.

Table 6. Performance measurements using EC sensor

Hours	Sensor EC	EC-Up
08.00	0.59	On
10.00	1.45	Off
12.00	1.28	Off
14.00	1.32	Off
16.00	1.30	Off

Figure 16. Performance measurement of EC sensor at 08.00 and 16.00 hours

Table 6 and Figure 16 show that at 08.00 hours the level of EC nutrition is still below 1 so that the EC-Up sensor is On. In this condition, the solenoid valve will open to drain EC water and raise the pH level to above 1. On the other hand, at 10.00, 12.00, 14,000, and 16.00 the EC nutrient level is already above 1 so that the EC-Up sensor is automatically in the Off status.

Table 7. Comparison between prototype hydroponic greenhouse-Arduino-Uno-standalone PV (proposed study) than previous studies

Authors	Methods/ Devices	Ph Level	EC Level	High/ Vol. Level	Temp. Level	Monitored by	Power Supply	Real Time	Green-house
Fitria Hidayanti, et.al. [1]	Arduino Uno	6-7	NA	18-20 cm	NA	LCD Display	Standalone PV-Battery	Yes	No
Helmy, et.al. [2]	Nutrient Film Technique	NA	1.4 mS or 700 ppm	NA	NA	Website	Grid PLN	No	No
Yuga Had-fridar Putra, et. al [3]	Microcontroller NodeMCU esp8266 v3	NA	600-800 ppm	5-10 cm	23^0-27^0 C	Website	Grid PLN	No	No
David Setiawan, et. al. [4]	Nutrient Film Technique	NA	NA	NA	NA	NA	Standalone PV-Battery	No	No
Muhammad Tirto Utomo, et.al [5]	Arduino Uno using Micro-controller ATMega16 U2	6-6.5	NA	6-8 cm	NA	LCD Display	Grid PLN	Yes	No
Muhammad Fakhruzzaini, et. al. [6]	Arduino Uno using Micro-controller ATMega328	5.5-7.5	NA	10-14 cm	NA	LCD 16 × 2 Display	Grid PLN	Yes	No
Ahmad Rifai, et.al. [7]	Arduino Uno using Fuzzy Logic Controller	NA	110-2000 µS/cm	10-100 mL	NA	LCD 16 × 2 Display	Grid PLN	Yes	No
Proposed Study	**Arduino Uno using Micro-controller ATMega328**	**6-7**	**1-2 mS/cm**	**NA**	**NA**	**LCD 20 × 4 Display**	**Standalone PV-Battery**	**Yes**	**Yes**

Note: NA = not available

Table 7 shows the prototype validation of the proposed hydroponic plant monitoring and control model compared to the previous seven prototypes. The parameters observed were pH level, EC level, high or volume water level, temperature level, measurement monitoring, hydroponic power supply, real-time measurement simulation, and the use of a greenhouse in a hydroponic system. In [1], Fitria Hidayanti, et. al have proposed Arduino Uno be supplied by Standalone PV-Battery to control the pH level and nutrient water level which their values monitored in real-time using an LCD. This prototype was able to control the pH level between 6-8 and the nutrition water level between 18-20 cm. In [2], Helmy, et. al. have proposed a Nutrient Film Technique supplied by the Indonesia Electric Company (PLN) grid to control the EC level of 1.4 ms or 700 ppm whose value was monitored wirelessly by the website. In [3], Yuga Hadfridar Putra, et.al have proposed the Arduino Uno be supplied by the PLN Grid to control the EC level, nutrition water high level, temperature, and its value to be monitored wirelessly by the website. This prototype was able to control the EC level between 600-800 ppm, a high level between 5-10 cm, and a temperature level of 23^0-27^0 C. The weakness of the prototype model in [2,3] was that it still used a database so that the measurement of performance parameters on both hydroponic systems still has a time delay. In [4], David Setiawan et.al have proposed Nutrient Film Technique to be supplied by Standalone PV-Battery. The weakness of this prototype only regulated the power supply from the PV-battery to the hydroponic system prototype and was still unable to control and monitor system performance parameters.

In [5], Muhammad Tirto Utomo, et. al proposed Arduino Uno using Microcontroller ATMega16 U2 be supplied by the PLN Grid to control the pH level, nutrient water level, and its value was able to be monitored in real-time using an LCD. This prototype was able to control the pH level between 6-6.5 and the nutrition water level between 6-8 cm. In [6], Muhammad Fakhruzzaini, et. al have proposed Arduino Uno using the ATMega328 Micro-controller supplied by the PLN grid to control the pH level between 5.5-6.5 and the nutrition water level between 10-14 cm, and the value is monitored in real-time with a 16 × 2 LCD. In [7], Ahmad Rifai, et.al have proposed Arduino Uno using the Fuzzy Logic Controller supplied by the PLN Grid to control the EC level and nutrition water level and its value to be monitored real-time using a 16 × 2 LCD. This prototype was able to control EC levels between 110-2000 µS/cm and nutrition water volume between 10-100 mL. In this study, the authors propose Arduino Uno using a Microcontroller ATMega328 supplied by Standalone PV-Batteries to

control pH and EC levels and monitor their values in real-time using a 20 × 4 LCD. This prototype was able to control pH levels between 6-7 and EC levels between 1-2 mS/cm. The advantage of the proposed model is that the character of the LCD is wider so that besides being able to display pH and EC parameter measurements, it is also able to display data on temperature, time, PV voltage, battery voltage, and TDS value. The proposed hydroponic system prototype also has been in the form of a greenhouse to keep the plant growth process taking place in the desired environmental conditions and at the same time preventing attacks from pests and diseases.

IV. CONCLUSION

The prototype model to monitor and control the pH levels and EC nutrition plant supplied by a standalone PV module-connected battery on greenhouse hydroponic systems has been implemented. The two sensors are connected to the Arduino Uno and relay control to drive four pumps, i.e. the water flow pump, EC pump, pH up pump, and pH down pump. The prototype model is able to monitor and control the pH of hydroponic plant water at the level between 6-7 using pH-up and pH-down sensor. This model is also able to monitor and control nutrition plant water over 1 mS/cm using EC sensor. The advantage of the proposed model is that the character of the 20 × 4 LCD is wider so that besides being able to display pH and EC parameter measurements, it is also able to display data on temperature, time, PV voltage, battery voltage, and TDS value. The proposed hydroponic prototype system also has been in the form of a greenhouse to keep the plant growth process taking place in the desired environmental conditions and at the same time preventing attacks from pests and diseases. The implementation of the EC sensor is only able to control the EC value if the value is less than 1 mS/cm. On the other hand, optimal plant growth in a hydroponic greenhouse system requires controlled EC values between 1-2 mS/cm. The use of an EC-down sensor to control the EC value so as not to exceed the 2 mS/cm value is proposed as future work to overcome this problem.

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