Design of flood warning prototype using ESP32 module-based ultrasonic sensors

Arnawan Hasibuan[1], Muhtadi Zahiri[1], Misbahul Jannah[1], Fahrian Roid[1], Rizky Almunadiansyah[1], Armen Abta[1], I Made Ari Nrartha[2]
[1]Department of Electrical Engineering, Faculty of Engineering, Universitas Malikussaleh, Lhokseumawe, Indonesia
[2]Department of Electrical Engineering, Faculty of Engineering, Universitas Mataram, Mataram, Indonesia

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ABSTRACT

Natural disasters such as floods can cause many losses to humans, such as material losses, trauma for the victims, and loss of life. Floods that occur can be caused by various factors such as human activity itself which results in changes in natural spatial planning, so the arrival of floods is also difficult to detect with certainty. Based on this, it is necessary to develop a technological innovation that helps provide a warning of the arrival of a natural disaster. The ESP32 microcontroller is one of the technologies that can be used to create an early warning system for the arrival of floods. The design and manufacture of this technology certainly involves modeling, algorithm planning, assembly of the components of the tools used, including wiring and mechanics as needed. This tool uses an internet of things (IoT) system with the help of an ESP32 microcontroller that supports integration via Wi-Fi and Bluetooth so that it can be connected to a smartphone device as a notification receiver in real time and accurately by notifying the water level which will be an indicator of potential flooding, so that people are more alert in the face of flooding to prevent and minimize the losses that will be experienced.

Corresponding Author:

Arnawan Hasibuan
Department of Electrical Engineering, Faculty of Engineering, Universitas Malikussaleh
Lhokseumawe, Indonesia
Email: arnawan@unimal.ac.id

1. INTRODUCTION

Erratic weather will greatly affect environmental conditions, one example is the high rainfall that occurs throughout the rainy season. High, uneven, and unpredictable rainfall can pose a threat of natural disasters in the form of floods where areas that have a lower elevation than the surrounding area will usually be inundated by water [1], [2]. In 2021 there were 5,402 natural disasters, of which 33.21% were floods, which occurred 1,794 times, followed by other natural disasters such as extreme weather with a percentage of 29.19%, which occurred 1,577 times, landslides with a percentage of 24.45%, which occurred 1,321 times, and 710 other natural disasters. The impact of these events resulted in 728 people died, 87 people missing, 14,915 people injured, 7,630,692 people suffered and displaced, 158,658 housing units damaged, 5,614 units of public facilities and services damaged [3].

Floods can occur at any time for different reasons, where floods can cause losses on a large enough scale, both in terms of material and infrastructure to casualties. In Indonesia itself, floods occur almost every year with handling is still not optimal [4], the type of flood that often occurs in Indonesia itself is flooding caused by overflowing rivers that affect people living around the river [5] floods cause many people to lose property, shelter and even result in loss of life [6] and also this natural disaster can traumatize the victims.

Until now, the absence of a system that can help people detect floods early makes the risk and impact of flooding itself still a serious threat to society [7].

Mulyana and Kharisma [8], a student of Informatics Engineering STMIK Tasikmalaya, has made a project "design of flood early warning tool with Arduino UNO R3 microcontroller" as well as paper [9], [10] which discusses the flood early warning system. However, this tool has a weakness because it uses a capacitive sensor that is inserted into the water, so that over time it will corrode the capacitor plate, and only uses a buzzer alarm to notify of flooding so that the information generated is still less efficient when received by the community. Umari *et al.* [11], a student of the College of Meteorology Climatology and Geophysics, made a final project entitled "design of a flood early warning system based on ultrasonic sensors and microcontrollers as a flood mitigation effort". In this research there are also weaknesses in the tools that have been made, namely only using buzzer alarms and liquid crystal display (LCD) as information notifications [12]. So this article will explain a new breakthrough by utilizing the ESP32 microcontroller module to make a more efficient and accurate flood detection system by using ultrasonic sensors as water surface level detectors, flow sensors as water discharge meters in rivers, and tipping bucket rain as rain intensity meters. The sensors used in this design are also better than capacitive sensors that are prone to corrosion due to direct contact with water [13], [14]. The development of existing technology is very supportive for the development of systems that can be a solution in dealing with the problems of human life including this flood disaster. The ESP32 microcontroller is one of the technologies that can be utilized to create a flood disaster mitigation system as discussed in this article to be able to help the community to be more alert in dealing with flood disasters, so that preventive action can be taken to reduce potential material losses to potential casualties such as damage to electronic equipment and vehicles [15].

2. DESIGN AND MANUFACTURE

Basically this research is a form of effort that can be made in solving problems of human life such as the problem of the impact caused by natural disasters, which in this research the problem of natural disasters to be resolved is the natural disaster of flooding. One form of innovation that can be developed regarding this matter is to design and build a tool that is able to provide information in the form of early warnings to the public about the possibility of flooding. Designing and building the hardware requires a process that starts from modeling, algorithm planning, assembling the components of the tools used, including wiring and mechanics that are in accordance with the needs. Then, designing and creating software that can be integrated with the built hardware can be done by planning a potential flood warning control algorithm using various forms of technology such as ultrasonic sensors, flow, and rain tipping sensors until the engineered program can meet the conditions according to its function. The working system of this potential flood warning tool will start every time the ultrasonic sensor detects a change in water level. Then there will be a broadcast message "safe water level/alert water level/dangerous water level", and every time rain tipping detects rainwater entering the collector, this tool will send a broadcast message "light rain/moderate rain/heavy rain/very heavy rain/heavy rain" to the user's cellphone.

2.1. Block diagrams

This section will explain in detail the research chronology, including research design, research procedures (in the form of algorithms, pseudocode or others) to the way of testing and data acquisition [16]–[18]. The description of the course of this research must also be supported by references, so that the explanation is scientifically acceptable [19], [20] Figures 1, 2, and Table 1 are presented in the center, as shown below and cited in manuscripts [16], [21]–[26]. Figure 2 shows the design of a flood detection tool.

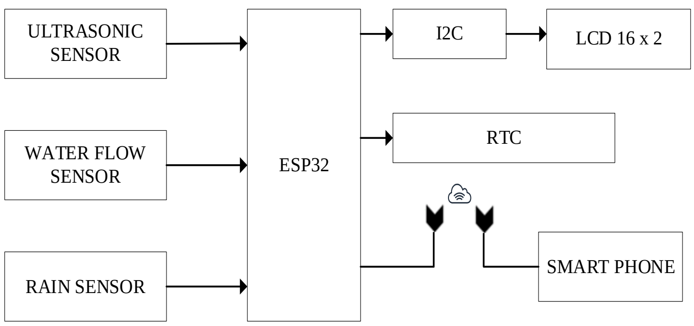

Figure 1. Block diagram

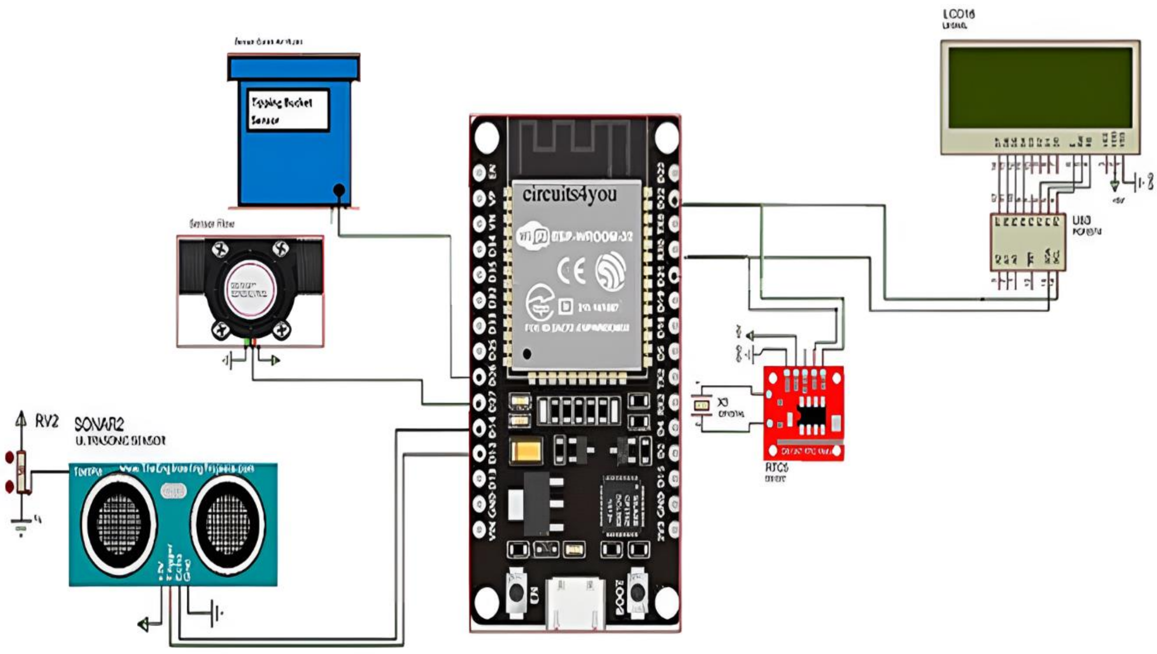

Figure 2. Flood detection tool design

Table 1. Tool specifications

Source	Information
Long	63.3 cm
Wide	33.3 cm
Tall	31.5 cm
Voltage	12 VDC
LCD	Liquid crystal displays 20×4
Microcontroller	ESP32
Time Information	RTC
Sensors	- Ultrasonic - Water flow - Rain tipping buckets

The implemented module is a potential flood warning tool that uses an ultrasonic sensor placed 31 cm above the surface of the water base which functions as a water level detector [27], [28]. When the ultrasonic sensor detects a change in water level, the system will send information to the smartphone in the form of water level status that has the potential to cause flooding [29], [30]. The process will repeat every day so that users do not need to check and monitor directly what indications on certain elements can cause accidents if the river water level rises suddenly [31], [32].

2.2. Tool design and manufacture

The system of the tool to be implemented requires a container to place the program design so that it can be executed by a microcontroller, in implementing the performance system of this tool will use the ESP32 microcontroller module as its data processor [33]. The ESP32 microcontroller has a Wi-Fi and Bluetooth module in which there are also pins that support the performance system as needed. Ultrasonic sensors are used to detect changes in river water level distance, flow sensors to detect river water flow [34] and tipping bucket rain as a rainfall detector in the area around the river. Where this process is carried out every day automatically and repeatedly [35].

2.3. Algorithm design

The algorithm of this research begins with the initialization of the program which involves reading the sensor inputs in stages. First, the ultrasonic sensor detects the water level; if detected, the system reads the water level, if not, other sensors are checked. Next, the water flow sensor detects the presence of water current and will read the current strength if detected, if not, the flow sensor will be rechecked. After that, the rain sensor detects rainfall, and if there is, the rainfall level will be recorded. After the data from all sensors is collected, the system reads the event time using the real time clock (RTC) and displays the information. The data obtained is then sent by the ESP32 to the user. The system continues to monitor whether the process has been completed; if so, the device enters standby mode, if not, the sensor will be reread. This algorithm ends after the entire process is complete. Below are each step of the Algorithm 1.

Algorithm 1. Systematic procedure
Start
1. Initializing programs
2. Read sensor input
3. Ultrasonic water level detection?
   a. If yes, then read the water level
   b. If not, read the sensor input
4. Flow sensor detects water flow?
   a. If yes, read the water current
   b. If not, read the water flow again
5. Rain sensor detects rainfall?
   a. If yes, read the rainfall rate
   b. If not, read the sensor input again
6. Read RTC?
   a. If yes, then displays the time of occurrence
   b. If not, read the sensor input
7. ESP32 Broadcast data to users
8. Is the process complete?
   a. If yes, tool standby
   b. If not, read the sensor input again
9. Finished

2.4. Input and output design

The design and performance system is implemented using an ESP32 module powered by an Xtensa dual core LX6 microcontroller, the ESP32 I/O ports can function as inputs and outputs for high and low power [36]. In order for the I/O ports to function as inputs or outputs, the double data rate (DDR) and ports must be configured. I/O port logic can be changed bytes or bits in a program. I/O is the most interesting and important part to look at, because it is the part of the microcontroller that deals with communication [37]. The coding program itself is made using Arduino software. For port planning on the ESP32 microcontroller can be seen in Table 2.

Table 2. Tool specifications

Pins/ports	Function	Information
Pins 12, 14	Inputs	Ultrasonic sensor input
Pins 27	Inputs	Flow sensor inputs
Pins 26	Inputs	Tipping bucket rain sensor input
Pins 21, 22	Output	Output LCD display 20×4, RTC

3. RESULTS AND DISCUSSION

3.1. Test results for measurement of power supply and voltage consumption

In this section, the results of testing the power supply and voltage consumption during the operation process will be explained. This test includes measuring voltage, current, power, and power factor to evaluate the performance and efficiency of energy use in the system being tested. The test data will be analyzed to determine the energy usage pattern and the potential savings that can be achieved. In addition, these results also provide an overview of the stability of the power supply during operation and its impact on the overall efficiency of the system.

The essence of the power supply measurement results table described in Table 3 is to show the proper and optimal voltage distribution for the various components in the system. Each device, such as sensors, RTC modules, LCD displays, and ESP32 microcontrollers, requires different voltages according to their specifications. Therefore, proper power supply management is essential to ensure that all devices operate efficiently without experiencing problems such as under or over-powering that can affect system performance.

Table 3. Power supply measurement results

Source	Voltage (DC)
Power supply	12 Volts
Ultrasonic sensors	5 Volts
Flow sensors	5 Volts
Tipping bucket rain sensor	5 Volts
Real time clock (RTC)	5 Volts
LCD display 20×4	5 Volts
ESP32 microcontroller	3.3 Volts

3.2. Overall system operational test results

3.2.1. Ultrasonic sensor test result

In this section, the results of ultrasonic sensor testing in detecting water levels will be explained. This test aims to evaluate the accuracy and consistency of the sensor under various conditions. The data generated such as detection distance and sensor response to changes in water levels. Analysis of the test results will provide an overview of sensor sensitivity, measurement error rate, and the effectiveness of the ultrasonic sensor as a water level monitoring tool in the system as a whole and so on. These results will also be compared with the sensor's technical specifications to assess its performance. The essence of the ultrasonic sensor test result table described in Table 4 is to show that this sensor has a good level of accuracy in detecting water level, with very small measurement errors and within acceptable tolerance limits. Although there are slight differences at some measurement points, overall the ultrasonic sensor is able to provide consistent and reliable results, making it effective for water level monitoring applications.

Our water level sensor underwent 15 rigorous tests, comparing its readings to actual measurements taken with a calibrated ruler. Results consistently showed the sensor's accuracy within a 1 cm margin of error, demonstrating its reliability across various conditions. While minor discrepancies may occur due to factors like electrical noise, water movement, or surface irregularities, the sensor's consistent performance within this narrow error range confirms its accuracy for most practical applications. Users should be aware of the potential 1 cm variation when relying on the sensor for critical measurements.

Table 4. Results of testing of ultrasonic sensors and measuring tools

Ultrasonic sensors (cm)	Measuring tool ruler (cm)	Error difference (mm)
1	0	-
2	1.9	0.1
3	2.9	0.1
4	4	-
5	5	-
6	6	-
7	7	-
8	8	-
9	9	-
10	10	-
11	11	-
12	11.8	0.2
13	12.6	0.4
14	13.9	0.1
15	15	-

3.2.2. Flow sensor test results

In this section, the results of the flow sensor test will be explained, which aims to evaluate the accuracy of the sensor in detecting water flow rates. Testing is done by comparing the sensor results to manual measurements or standard measuring instruments. The data obtained will be analyzed to see the consistency of measurements at various levels of water flow and possible measurement errors. The results of this test provide an overview of the sensor's sensitivity in responding to changes in flow and its performance in real-time water flow rate monitoring applications.

Table 5 explains the relationship between water level, flow rate, and measurement time. The flow sensor is used to measure the water flow rate at various water levels, which is then compared with the time recorded using a stopwatch. The purpose of this test is to evaluate the performance of the flow sensor in detecting changes in water velocity when the water level rises or falls. In general, Table 5 provides an overview of how the sensor responds to changes in water flow conditions accurately. The data collected helps in understanding the pattern of water flow rates at various heights and the time required for measurement at each level. These results are important for assessing the reliability and sensitivity of the flow sensor in water flow monitoring and control applications.

Table 5. Testing results of flow sensors and measuring tools

Water level (cm)	Flow (m/s)	Stopwatch (s)
15	6.7	00:19:65
14	6.7	00:20:52
13	3.9	00:21:07
12	1.9	00:22:73
11	1.8	00:24:09
10	0.6	00:25:48
9	1.4	00:25:96
8	4.6	00:26:43
7	5.9	00:29:69
6	7.1	00:29:78
5	11.8	00:35:48
4	6.8	00:35:71
3	0.4	00:48:65
2	1.5	00:52:76
1	0.1	03:23:68

We tested the flow sensor using a ruler and stopwatch. We filled it with water and measured how long it took for the water level to drop by 1 cm. The sensor readings for flow rate were around 6.7 m/s in most tests. There was some variation in flow rate readings and the time it took for the water to drain.

3.2.3. Rain tipping bucket test results

Based on the test results on the rain tipping bucket sensor carried out in Table 6 using a 60 ml for each 5 ml water drop, 3 tips and their multiples were obtained. In the first test, the sensor was given a drop of 5 ml of water volume and the sensor got a reading of 3 tips, by calculating the volume of water dripped into the sensor per collector area multiplied by the number of tips:

$$CH = \frac{V}{L_k \times T_t} \quad (1)$$

$$5 \div (19.25 \times 3) = 0.0865\ mm$$

where CH is rainfall (mm), V is volume of water (ml), L_k is collector area (m^2), and T_t is tipping amount.

The result was a rainfall of 0.0865 mm, in the second test, the water dripped with spet was 10 ml but the sensor got a reading of 7 tipping, where there was a difference of 1 tipping:

$$10 \div (19.25 \times 7) = 0.0742\ mm$$

Table 6. Examination results of rain tipping bucket and measuring tools

Water volume (ml)	Lots of tips	Rainfall height (mm)	Error (mm)
5	3	0.0865	-
10	7	0.0742	0.0123
15	9	0.0865	-
20	12	0.0865	-
25	16	0.0811	0.0054
30	18	0.0865	-
35	22	0.0826	0.0039
40	25	0.0831	0.0034
45	28	0.0834	0.0031
50	30	0.0865	-
55	33	0.0865	-

Obtained results of rainfall 0.0742 mm. In the third test, 15 ml of water was dripped, the sensor read 9 tips and obtained a result of 0.0865. The highest difference was obtained in the 2 cm test which showed a difference in rainfall of 0.0123 mm. There are several factors that cause this error, namely the mechanics on the seesaw sensor not working properly, errors in the electronics that occur between the magnets and the hall effect sensor, and the slope of the terrain.

3.3. Overall system testing results

This section presents a summary of the results of our comprehensive testing of our system. We will discuss the key findings from the various types of tests that have been performed, covering system functionality, performance, security, and compatibility. This analysis aims to assess system readiness, identify areas for improvement, and ensure that all components are functioning according to expected specifications

Table 7 presents the results of water level tests at various surface elevations, which can be used in flood monitoring or warning systems. The data is divided into three main categories: safe (1-5 cm), alert (6-11 cm), and dangerous (12-15 cm). This classification allows for informed decision-making based on the detected water levels, ranging from normal conditions to situations requiring immediate action. This kind of information is invaluable for flood risk management and public safety, helping relevant authorities plan appropriate responses to changes in water levels.

Based on the tests carried out on the ultrasonic sensor in detecting the water surface level when the water discharge increases due to rainfall getting a good and fast response, the higher the water level read by the sensor, the ESP32 will send a broadcast message in the form of a "danger water level" message. When the water level reaches 11-15 cm, when the water decreases continuously and the sensor detects a water level of 5-1 cm, the ESP32 will again send a broadcast message in the form of a "safe water level" message. Messages sent by ESP32 from ultrasonic sensor readings include safe water level/alert water level/danger water level.

Table 8 shows the results of a test that classifies rainfall intensity based on the number of water droplets, ranging from drizzle to very heavy rain. This classification system divides rainfall into five different categories, providing a more measurable understanding of weather conditions. This kind of information is invaluable for a variety of applications, including flood early warning systems, agricultural planning, and water resource management. With this data, scientists can make more accurate predictions about weather impacts and take appropriate action, as well as support long-term climate research and understanding of rainfall patterns in a region.

The tests showed the rain sensor works well and reacts quickly to rainfall. It sends alerts to a device (ESP32) based on the amount of rain. Light rain tips 1-17 times, triggering a "light rain" message. Heavier rain with more tips (166-198) triggers an "extreme rain" message. However, the sensor resets its rain data each day at midnight. So, moderate rain throughout the day might be misreported as heavy rain near midnight.

Table 7. Test results at low water level

Water surface level	Information
1 cm	Safe water level
2 cm	Safe water level
3 cm	Safe water level
4 cm	Safe water level
5 cm	Safe water level
6 cm	Standby water level
7 cm	Standby water level
8 cm	Standby water level
9 cm	Standby water level
10 cm	Standby water level
11 cm	Danger water level
12 cm	Danger water level
13 cm	Danger water level
14 cm	Danger water level
15 cm	Danger water level

Table 8. Test results on rainfall

Lots of tips	Information
1	Drizzle
8	Drizzle
11	Drizzle
17	Drizzle
20	Moderate rain
25	Moderate rain
32	Moderate rain
39	Moderate rain
46	Moderate rain
53	Heavy rain
61	Heavy rain
77	Heavy rain
86	Heavy rain
93	Heavy rain
106	Very heavy rain

The analysis we did helps us understand flood risks and how to warn people. We can use this information to build an innovative flood early warning system for smartphones in flood-prone areas. This system will alert people about potential floods, helping to reduce the impact of flooding on communities.

4. CONCLUSION

Early flood warnings are crucial! New technologies can help us prevent disasters. One way is to develop a flood warning system that alerts communities about potential flooding. Designing and building the hardware involves modeling, planning algorithms, assembling components, wiring, and mechanics. Integrating software with the hardware includes planning a flood warning control algorithm using sensors like ultrasonic, flow, and rain tipping. The system triggers a message when the ultrasonic sensor detects water level changes and sends alerts about rain intensity when rain tipping sensors detect rainfall. This tool, which will be built and installed around the main location that causes flooding, will later be able to provide information in the form of an early warning to the smartphone community that there is a possibility of a flood natural disaster, this effort is expected to be a solution to reduce the impact that will be felt by the community from the occurrence of a flood natural disaster.

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BIOGRAPHIES OF AUTHORS

Arnawan Hasibuan Associate Professor at Faculty of Engineering in Universitas Malikussaleh, Aceh, Indonesia. He works as senior lecturer and researcher at Undergraduate Program of Electrical Engineering and Master Program of Renewable Energy Engineering. Interest in research in the field of power systems, renewable energy, and system control. Apart from teaching, he is also active as chief editor at the Journal of Renewable Energy, Electrical, and Computer Engineering (JREECE) and the Jurnal Solusi Masyarakat Dikara (JSMD). He can be contacted at email: arnawan@unimal.ac.id.

Muhtadi Zahiri student of Department of Electrical Engineering in Faculty of Engineering at Universitas Malikussaleh, Aceh, Indonesia. He is also a research assistant and practicum assistant at the Unimal Electrical Engineering Laboratory. He can be contacted at email: muhtadi.170150098@mhs.unimal.ac.id.

Misbahul Jannah Lecturer at the Faculty of Engineering, Malikussaleh University, Aceh, Indonesia. He works as a senior lecturer and researcher in the Electrical Engineering Undergraduate Program. Field of expertise in electrical power systems. She can be contacted at email: mjannah@unimal.ac.id.

Fahrian Roid student of Department of Electrical Engineering in Faculty of Engineering at Universitas Malikussaleh, Aceh, Indonesia. He is also a research assistant and practicum assistant at the Unimal Electrical Engineering Laboratory. He can be contacted at email: fahrian.200150011@mhs.unimal.ac.id.

Rizky Almunadiansyah student of Department of Electrical Engineering in Faculty of Engineering at Universitas Malikussaleh, Aceh, Indonesia. He is also a research assistant and practicum assistant at the Unimal Electrical Engineering Laboratory. He can be contacted at email: rizky.200150036@mhs.unimal.ac.id.

Armen Abta student of Department of Electrical Engineering in Faculty of Engineering at Universitas Malikussaleh, Aceh, Indonesia. He is also a research assistant and practicum assistant at the Unimal Electrical Engineering Laboratory. He can be contacted at email: armen.200150180@mhs.unimal.ac.id.

I Made Ari Nrartha Associate Professor at Faculty of Engineering in Mataram University, Nusa Tenggara Barat, Indonesia. Interest in research in the field of power systems, renewable energy, and system control. He can be contacted at email: nrartha@unram.ac.id.