Design of an Arduino-Based Electrical Power Optimization Monitoring System for Wind Power Plants

Siti Anisah, Zuraidah Tharo

Abstract

Wind is a renewable energy that we can utilize through Wind Power Plants. The power generated by wind turbines comes from the wind that drives the windmills and wind turbines. Several factors that affect the performance of wind turbines are weather, humidity, temperature and the position of the windmill. Wind turbines can work optimally if we can monitor every current and voltage generated from the Wind Power Plant. Therefore, a tool was created that can monitor and display the amount of voltage and current generated by the Wind Turbine. This tool uses a PZEM-004T sensor to measure current and voltage. The sensor measurement results are processed by the Arduino Nano R3 then the data will be displayed on the LCD and ESP-01 Chip to wifi then the data will be sent to the Thingspeack cloud server to display the current and voltage on the web that we can open via Laptop and Android.

Keywords: Wind Turbine, PZEM-004T, Arduino Nano R3, Chip ESP-01, LCD, Android

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Introduction

Indonesia, the most archipelagic country, has the second-longest coastline on the planet (after Canada), at 99,093 km, expanding from approximately 91,000 km previously, with wind speeds ranging from 7.2 km/h to 21.6 km/h. These conditions are ideal for small-scale wind power generation. Wind energy is a renewable energy source, meaning it can be rapidly regenerated by natural processes. Renewable energy offers several advantages, including being free, unaffected by global warming, rising fuel prices, minimal waste, and relatively easy to source. Wind speed is a linear velocity obtained by converting the rotational speed obtained by a rotary encoder into a linear velocity [1]. Wind speed is always changing, so to determine how much energy the wind contains, it is necessary to process wind speed information using measured data. Therefore, we must utilize renewable energy production appropriately and even produce it to address future problems. The heat the Earth receives from the sun must first pass through the atmosphere [2] [3].

Wind energy is one of the smartest sources of environmentally friendly energy generation. Wind energy can provide a reasonable answer to the energy emergency and global change (Dhawale, 2017). Based on the potential of wind, it can be utilized to produce electrical energy that can be used to light houses on the coast and surrounding areas, so this thesis is related to the creation of a wind power generation system. The main devices of a wind power plant are turbines and generators. A turbine is a rotating mechanical device that gets energy from the wind flow, while a generator is a device that converts kinetic energy into electrical energy. With certain configurations, turbines and generators can produce sufficient voltage and current to charge batteries. We can utilize the potential of wind for small-scale generation so that this device can charge electrical energy to batteries [4].

The performance configuration of wind turbines and generators requires a device to monitor their power. This is the basis for the idea of creating a wind turbine power monitoring device based on a digital signal.

Literature Review

The electricity sector plays a crucial role in developing countries, not only as a means of meeting needs but also as a foundation for future technological progress and development. Increasing populations and urbanization have resulted in increased energy demand, placing significant pressure on domestic resources, resulting in a dependency on electricity. The use of fossil fuels provides a temporary solution to the energy crisis but imposes additional costs on consumers. Developing countries also face challenges due to the inability to meet energy demand and supply, either due to underdeveloped power generation sectors or disruptions in transmission capacity, resulting in electricity shortages. In 2019, approximately 570 million people in developing countries lacked access to electricity [4].

Current consumption of fossil fuels will result in the exhaustion of oil, natural gas and coal resources in 50.7, 52.8 and 114 years respectively. Globally, our electricity needs are met by power plants that are primarily powered by oil, followed by coal, gas, and then hydroelectricity. The global energy mix includes over 80% of electricity consumption generated from fossil fuels. Fossil fuels are responsible for almost ¾ of global greenhouse emissions [5], [6]. The world is currently facing major environmental and energy challenges, making the transition to renewable and sustainable energy sources crucial.

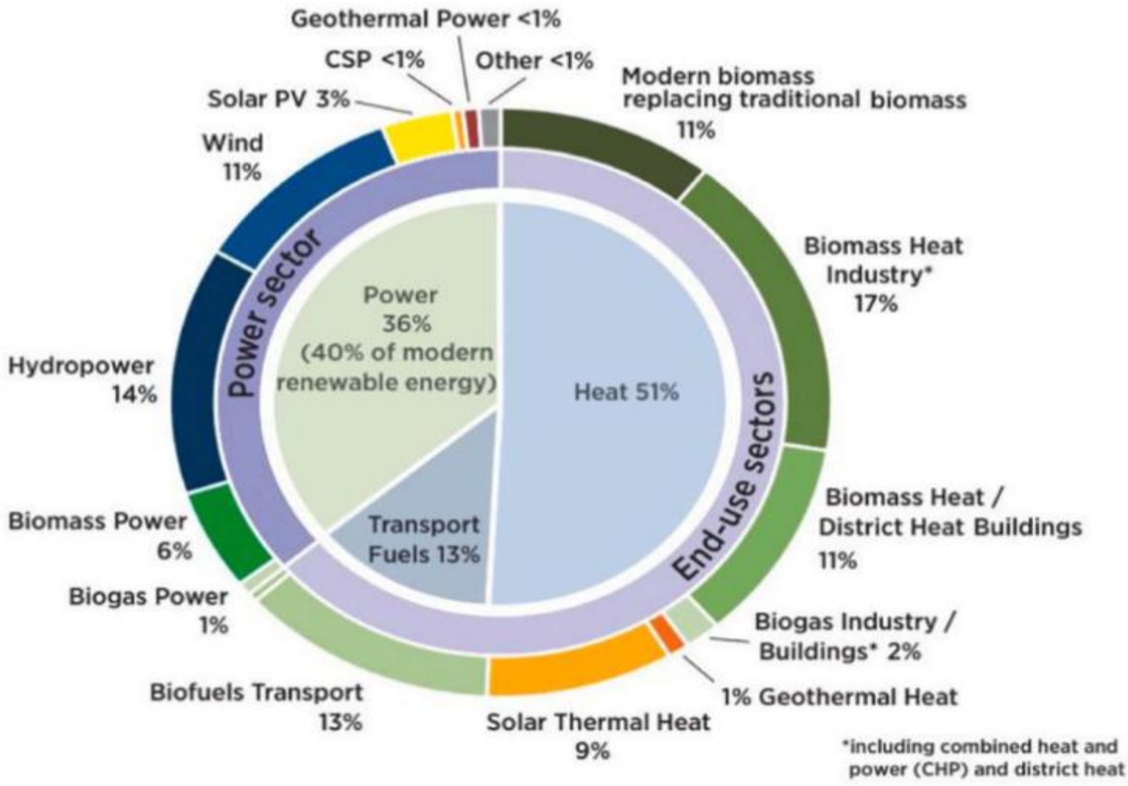

Figure 1. Percentage of New Renewable Energy

Solar and wind energy are abundant renewable resources available globally, making them important alternatives to conventional fuels due to their sustainability, affordability and wide accessibility [7]. The adoption of solar energy and wind turbines has seen rapid growth in recent years, with many countries setting large targets to increase reliance on renewable energy. Wind power plants are a renewable energy source that is increasingly popular worldwide as a solution to reduce dependence on fossil fuels and lower greenhouse gas emissions. The abundance and renewable nature of wind energy makes an attractive option for meeting global energy needs [8], [9].

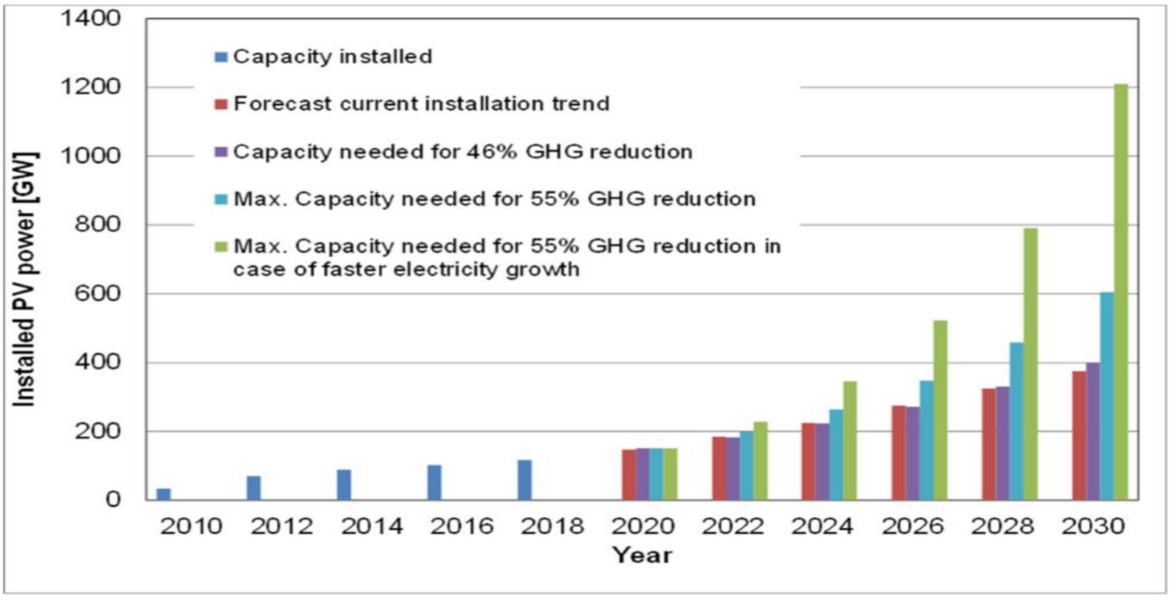

Figure 2. New and Renewable Energy Growth Target

An effective electrical power monitoring system is necessary to ensure that wind turbines operate at optimal conditions and to detect potential problems early that could lead to operational losses or damage to the system. The use of Arduino Uno-based monitoring technology offers an economical and easy-to-implement solution for this purpose. The Arduino Uno is a flexible and popular microcontroller platform that can be used to develop a variety of monitoring applications at low cost and with minimal complexity [10]. The Arduino Uno is equipped with various features that enable the integration of sensors to measure critical parameters such as wind speed, voltage, current, and frequency of the wind turbine's power output. Data obtained from these sensors can be processed and analyzed to provide accurate, real-time information on the operational conditions of the wind turbine. Furthermore, the wireless communication capabilities of the Arduino Uno Arduino Uno allows data to be sent to other devices for remote monitoring, so operators can take necessary actions quickly and efficiently. Implementing an Arduino Uno-based monitoring system in a wind turbine has the potential to improve operational efficiency and reduce maintenance costs by detecting anomalies and predicting failures before they occur. Case studies conducted on various wind turbine models show that this system is capable of delivering reliable and consistent performance and can be adapted to meet the specific needs of various types of wind turbines [11], [12].

2.1 Understanding Wind Energy

Several studies have conducted research related to wind turbines, including: Bambang Setioko, "The rise in fuel prices has encouraged people to seek new, affordable and readily available alternatives. This has been exploited as a means of exploration and use as the primary driver for electric generators to generate electricity." Procedures for handling and checking information for wind turbine assembly are developed by collecting information on the number of fans, point size, wind speed, and number of shocks. Relapse checking is used as a strategy to establish a practical relationship between two factors, specifically the independent and subordinate factors. Given a specific wind power and speed, the rotor's reach, size, height, and rotational speed can be determined. The rotor area is significantly influenced by the power coefficient. The design rotor rotational speed can be determined after the rotor width is determined, and the speed is not entirely determined. This study used a width-to-flatness ratio of 0.1; 0.8; 0.8. The result is a table of force, wind speed, rotor area, density, height, and rotational speed that can be used as the basis for wind turbine design [13].

Wind is moving air caused by the Earth's rotation and differences in air pressure. Wind moves from areas of high pressure to areas of low pressure. When heated, air expands. The expanded air becomes lighter and rises. When this occurs, air pressure decreases because there is less air. The surrounding cooler air flows to the area of low pressure. The air contracts, becomes heavier, and sinks to the ground. Above the ground, the air heats up again and rises again. This rising flow of warm air and sinking cold air is due to convection [14].

Wind power refers to the collection of useful energy from the wind. In 2005, wind power generator capacity was 58,982 MW, representing less than 1% of global electricity consumption. Although still a minor source of electricity in most countries, wind power production more than quadrupled between 1999 and 2005. Most modern wind power is generated in the form of electricity by converting the rotation of turbine blades into electric current using an electric generator.

2.2 Wind Potential in Indonesia

Based on Government Regulation No. 79 of 2014 concerning National Energy Policy, Indonesia set a target to achieve a new and renewable energy mix of 23% by 2025 and 31% by 2050. The target capacity for wind power plants (PLT-Angin) by 2025 was 255 MW. However, as of 2020, the installed capacity of PLT-Wind had only reached approximately 135 MW, with

75 MW in Sidrap and 60 MW in Janeponto. This indicates that wind energy development in Indonesia still faces significant challenges in achieving this national target.

The availability of accurate wind energy potential maps throughout Indonesia is essential as a first step in identifying and selecting locations for wind energy projects. These maps provide crucial information on wind characteristics in various regions, such as average wind speed, maximum and minimum speeds, which can be converted into annual power density and energy maps (in kWh or W/m²). This information is extremely useful as a basis for determining project locations and selecting appropriate turbine technology [15].

Based on the results of wind speed distribution mapping, high wind speeds (6-8 m/s) in onshore areas occur along the southern coast of Java, South Sulawesi, Maluku, and East Nusa Tenggara (NTT). Meanwhile, in offshore areas, wind speeds exceeding 8 m/s were detected offshore in Banten, Sukabumi, Kupang, Wetar Island, Jeneponto Regency, and Tanimbar Islands Regency. The maximum wind speed occurs in June, July, and August during the Australian monsoon season, while the minimum speed occurs in March, April, and May during the transition from the Asian monsoon to the Australian monsoon [16].

2.3 Types of Wind Turbines

A wind turbine is a windmill used to generate power. These wind turbines were originally designed to meet the needs of farmers for rice processing, water management, and other purposes. Many wind turbines of the past were built in Denmark, the Netherlands, and other European countries and were also called windmills. These included horizontal axis wind turbines (tash) with a primary rotor shaft and an electric generator at the highest point of the apex. Small turbines are coordinated by a direct wind vane, while larger turbines generally use a wind sensor combined with a servo motor. Most wind turbines have several types of gearboxes, including: gears that change the speed of the rotor shaft from a slow one to a faster one .

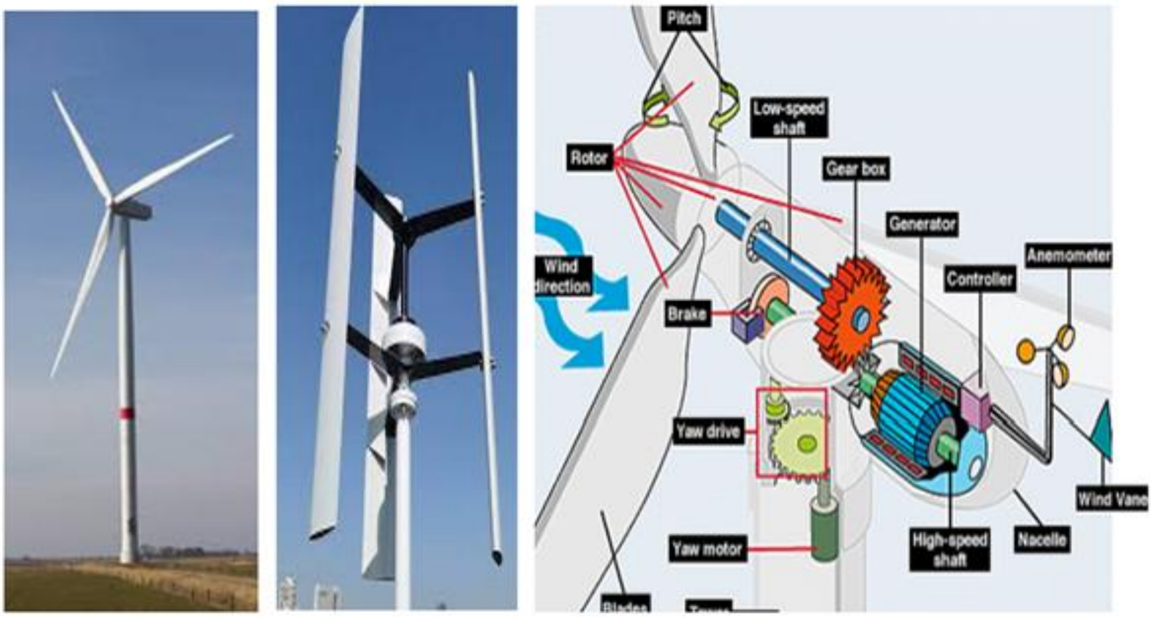

Figure 3. Wind Turbine and Wind Turbine Components

2.4 Arduino Uno

The Arduino Uno is a board that uses the ATmega328 microcontroller. It has 14 digital pins (6 pins can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power supply connector, an ICSP header, and a reset button [17]. The Arduino Uno contains everything needed to support a microcontroller. Simply connecting it to a computer via USB or applying DC voltage from a battery or AC-to-DC adapter is enough to get it working. The Arduino Uno uses an ATmega16U2 programmed as a USB-to-serial converter for serial communication with the computer via the USB port [18], [19].

2.5 Thingpeak Iot Data Acquisition Application

ThingSpeak is an open-source "Internet of Things" application and API for storing and retrieving data from things using HTTP over the Internet or a Local Area Network.

The Internet of Things (IoT) provides access to a wide range of embedded devices and web services. ThingSpeak is an IoT platform that allows us to collect, store, analyze, visualize, and act on data from sensors or actuators, such as Arduino, Raspberry Pi, BeagleBone Black, and other hardware. For example, with ThingSpeak, we can create sensor-logging applications and location tracking applications.

ThingSpeak functions as a data collector, collecting data from node devices and also allows the data to be captured into a software environment for historical data analysis. The main element of a ThingSpeak activity is a channel, which contains a data field, a location field, and a status field. Once we create a ThingSpeak channel, we can write data to the channel, process it, and view it.

Research Methodology

The method used in this research is design and analysis, namely designing a model or creating a research object in the form of hardware and software. The object is then researched and tested. The test results are analyzed to obtain secondary data and specifications for the designed device. In this case, the research object is an Arduino-based wind turbine power IoT monitoring system. The following explains the methodology, including component use, block diagrams, system operating principles, and flowcharts.

A block diagram is the foundation of a circuit system, describing its operation and functions. This stage involves designing and building the system, including creating a block diagram and defining and developing algorithms for software design. The block diagram explains the input, processing, and output components used in Arduino-based IoT monitoring of wind turbine power. System input comes from two types of sensors: a current sensor and a voltage sensor. The current sensor and voltage divider circuit function to detect the power used by the charge controller and battery. In the Output section there is an LCD that functions to display power data from sensor measurements. The ESP-01 Wifi module will send sensor measurement data from the Arduino to the thingspeak cloud server, while the thingspeak main page will function to display the power from the wind turbine, charge controller and battery. The Arduino uno microcontroller as a data processor from the sensor and the LM2596 regulator to turn on all system devices.

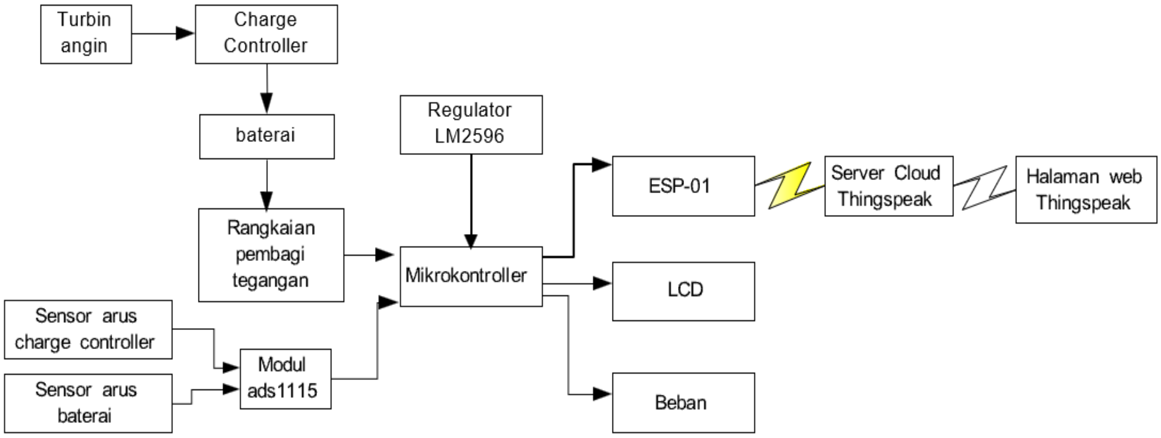

Figure 4. Arduino Uno Microcontroller

The system operates based on a pre-designed program and follows a pre-designed algorithm. When the system is activated, the program begins to run. The microcontroller, using the ESP-01 chip, attempts to connect to the SSID corresponding to the Wi-Fi SSID entered into the microcontroller program. Once connected to the Wi-Fi SSID, the system measures the current from the current sensor. The battery output voltage ranges from +- 12 volts, while the Arduino ADC pin can only receive this voltage.

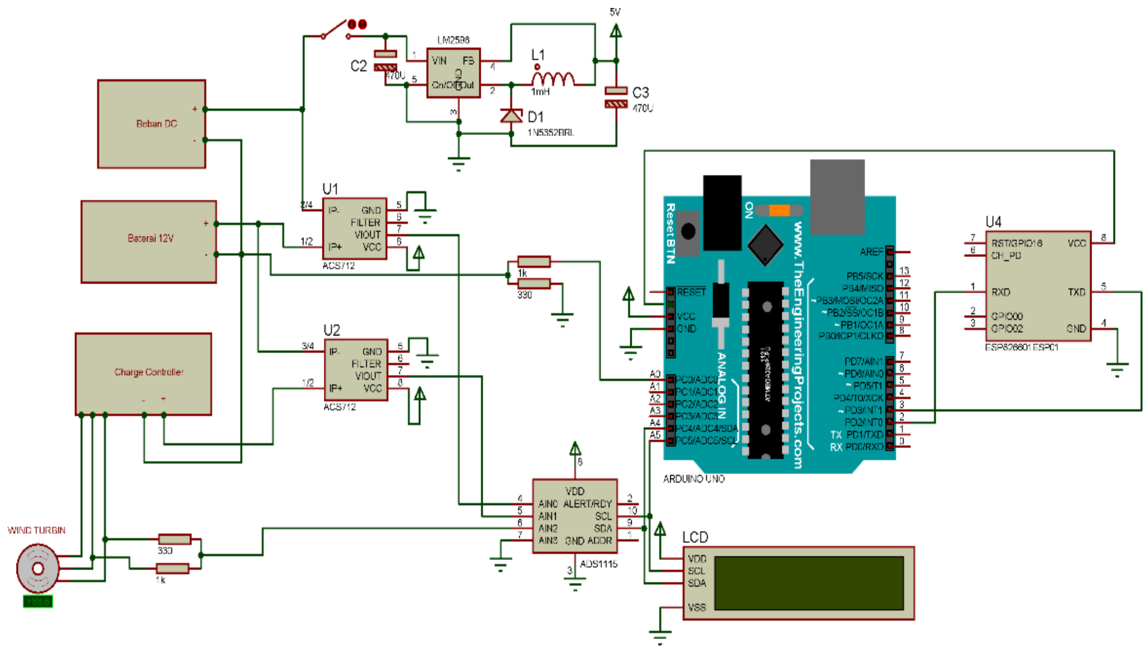

Figure 5. System Measures the Current From the Current Sensor

Results

The research results are an analysis of the implementation of the research that has been carried out, the research results are in the form of a prototype model of a wind turbine monitoring system consisting of a 5-blade wind turbine, charge controller, battery and monitoring system. The wind turbine blades will rotate if there is a blow towards the wind turbine, the blades will rotate the generator inside the wind turbine which will produce an electric voltage which then the output of the voltage will be connected to the charge controller using a cable. The charge controller will control the electric power from the wind turbine to remain stable to recharge the battery even though the electric power generated by the wind turbine is unstable and functions as a safety so that the battery voltage does not flow to the wind turbine generator when the wind turbine does not produce any electric power at all. The monitoring system consists of analog and digital electronic circuits. The system consists of a power supply, current sensor, voltage sensor, Arduino microcontroller, ESP-01 chip, LCD. The system consists of two AC712 current sensors, each measuring the charge controller current when actively recharging the battery and the battery output current when a load is connected. A voltage divider circuit is used to measure battery voltage. The Arduino Uno also controls data transmission to the LCD to display the current and voltage sensor readings. The ESP-01 chip operates in areas related to data transmission via Wi-Fi, including measurement data. Sensors processed by the Arduino Uno are sent to the ESP-01 chip and then forwarded to the Thingspeak server via Wi-Fi. To determine the system's performance and functionality, this chapter will conduct a series of tests, from component functionality to overall testing.

Figure 6. Prototype Design Results for IoT Monitoring of Wind Turbine Electric Power

Current Sensor Testing

The ACS712 current sensor operates on Hall effect technology. This sensor features a low-offset linear Hall circuit with a single path. Made of copper. This sensor works by reading the current flowing through the copper wire inside, which produces a magnetic field that is captured by the integrated Hall IC. The flow of electric current that produces a magnetic field that induces the dynamic offset cancellation section of the ACS712, which is amplified by an amplifier and converted through a filter into a proportional voltage.

To measure the current passing through this sensor, the voltage formula used on the pinout = 2.5 ± (0.185 x I) Volts, where I = the detected current in Amperes. Testing to determine whether the sensor is working and functioning properly can be done by supplying a power supply to the sensor and then applying a variety of resistor loads. The voltage value at the output is read by the Arduino and displayed on the serial monitor. If a load is applied to the sensor input but the output voltage remains unchanged, the sensor is not working. The following are the sensor test results.

Analysis: The output value issued by the current sensor is directly proportional to the input load passing through the sensor.

Table 1. Test the Voltage Divider Circuit

No	Resistor value (ohm)	Source voltage (volt)	Calculation flow (ampere)	Sensor reading value (ampere)	% error
1	3	12,83	4,28	4,50	1,74
2	5	12,74	2,55	2,80	1,98
3	7	12,80	1,83	2,03	1,57
4	10	12,76	1,28	1,54	2,07
5	13	12,81	0,99	1,15	1,29
6	16	12,85	0,80	0,92	0,91
7	20	12,77	0,64	0,75	0,87
8	25	12,78	0,51	0,66	1,16
9	30	12,80	0,43	0,54	0,89
10	35	12,80	0,37	0,45	0,66
Average					1,31

Test the voltage divider circuit by supplying power to the voltage divider circuit. The voltage value at the output is connected to the positive probe of the multimeter, and the negative probe is connected to the power supply ground or the voltage divider circuit ground. The voltage value at the output of the voltage divider circuit is also read by the Arduino and displayed on the serial monitor. The following are the results of the voltage divider circuit test.

Table 2. Voltage Sensor Measurement Results (voltage divider)

No	Multimeter Reading (volts)	Output Arduino (volt)	% error
1	0,00	0,00	0,00
2	1,11	1,18	3,50
3	2,14	2,10	1,33
4	3,10	3,18	2,00
5	4,15	4,05	2,00
6	5,14	5,28	2,33

The power supply used is a 12V DC VRLA battery. The LM2596 regulator is used to provide a constant 5-volt voltage supply to the system and sensor circuits. Testing is carried out by providing an input supply and using a multimeter to measure the input and output voltages on both circuits. The input voltage supply comes from a 12-volt DC battery.

Table 3. Power Supply Circuit Voltage Measurement Results

Kondisi	Input VCC (volt)	Output LM2596 (5 volt)
Tanpa Beban	12,10	5,00
Dengan Beban	11,80	4,99

Analisa: Dari pengujian diatas terlihat bahwa hasil pengukuran pada rangkaian regulator diperoleh hasil antara output tegangan tanpa beban dibandingkan dengan beban terdapat perbedaan yang tidak signifikan walaupun dibebani dengan rangkaian arduino dan sensor.

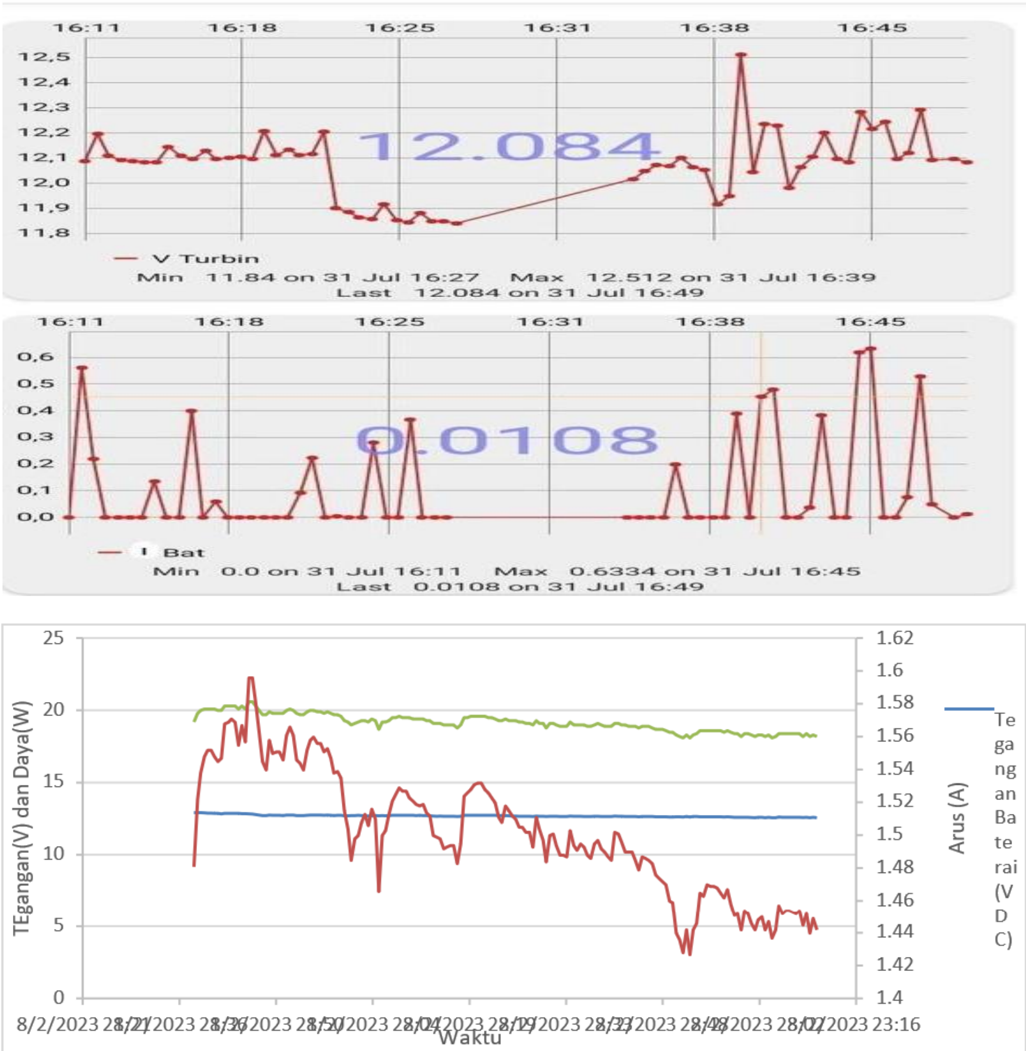

Figure 7. Voltage and Current in Thingspeak Application

Conclusion

This research concludes that:

1. The Internet of Things (IoT) can facilitate user monitoring of electrical power conditions in wind turbine power generation systems.
2. The Thingspeak platform can be used as a user interface for monitoring electrical power.
3. Differences in measurement values between PZEM sensors and measuring instruments.
4. The NodeMcu ESP-01 module can be used to connect Arduino and IoT systems using AT command communication.

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