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Analysis of the Electric Power Monitoring System in Wind Power Plants Based on Arduino Uno

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Abstract - The Wind Power Plant is a renewable energy solution that can reduce dependence on fossil fuels and reduce greenhouse gas emissions. However, to ensure operational efficiency and reliability, an effective monitoring system is needed to monitor and manage the electrical power produced. This resear chaims to develop and analyzean electrical power monitoring system at PLT Busing the Arduino Uno platform. The proposed monitoring system consist sofsophisti cated sensors integrated with Arduino Unotocollect real-time data regarding wind speed, output voltage, current and turbine operational conditions. The data collectedby these sensor sissentto the Arduino Uno, which then processes andstores thedata for further analysis. Additionally,this data canbe transmitted toot her devices for remote monitoring via a wire less communication module. Algorithms were developed to analyze and display critical information about turbine performance, including anomaly detection and failure prediction. System testing was carried out on a small-scale PLTB model, and the results showed that this system was able to monitor changes in electrical power with high accuracy and fast response time. Implementation of this Arduino Uno-based monitoring system also enable searly detection of potential problems, so that preventive action can be taken to reduce downtime and increase operational efficiency. The results of this research showthat using Arduino Uno as a platform for the electrical power monitoring system at PLTBis not only effective in collecting andanalyzing data,butis also economical andeasy to implement.This system canbeeasily adaptedand expanded to suit the specific needs of various types of PLTB. In conclusion, the Arduino Uno-based monitoring system offers an innovative and practical solution to improve the performance and reliability of PLTB.

Keywords : Wind Energy, Monitoring, Electric Power, Arduino Uno

1. INTRODUCTION

Electricity sector has an important role in developing countries, not only as an effort to meet needs but also becomes the basis for future technological progress and development . Increasing population and urbanization have an impact on energy demand which also increases, putting great pressure on domestic resources, resulting independen ceon electricity [1].Theuse of fossil electricity providesa temporary solution to the energy crisis but causes consumer stoin curad ditional costs. Developing countries also experience problem sdueto the inability to meet energy demand and supply, eitherduetounder developed power generation sectors or cessation of transmission capacity which results in electricity shortages. In 2019, around 570 million peoplein under developed countries didnothaveaccessto electricity [2]. Current consumption of fossil fuels will resultin the exhaustion of oil, natural gas and coal resources in 50.7, 52.8 and 114 years respectively [3].

Globally, our electricity needs are met by electricity generation, most of which comes from oil, followed by coal, gas, and then hydro electric power plants. The world wide energy mixincludes morethan 80% of electricity consumption generated from fossil fuels [4]. Fossil fuel sareres ponsibleforalmost ¾ of global green house emissions [4],[5]. The world iscurrently facing major challenges related to the environment and energy, so switching to renewable and sustainable energy sources is very important. Among the promising options, solar and wind energy are the most prominent, as they have the potential to significantly reduce green house gas emission sandreduce dependenceonhydrocarbons[6]. Solar and wind energy area bundant renewable resources available globally, making them important alternatives to conventional fuels due to their sustainability, affordability, and wide accessibility [7] . The application of solar energy and wind turbines has experienced rapid growth in recent years, with many countries setting large targets to increase their dependence on renewable energy [8] .

Indonesia is the country with the most islands and has the second longest coastline on the planet (after Canada), with a lengthof 99,093km, whichhasexpandedfrom previously around91,000km with windspeedsranging from 7.2km/hto21.6 km/h. The seconddition sareideal forusing small-scale wind powerplants.Wind speedisalinearspeedthatcanbeobtainedby converting the rotation speed obtained by the rotary necoder into linear speed. Wind speed is always changing, so to find out howmuch energy the wind contains,it isnecessaryto process wind speedinformation byutilizing measuredin formation.The heat received by the earthfrom the sun must pass through the atmosphere first, causing differences in heat in several parts of the atmosphere and the air on earth due to the influence of the gases that make up the layers of air.Wind energy is one of the smartest sources of environmentally friendly energy creation. Wind energy can provide a reasonable answer to the energy emergency and world change [9] .

Wind Power Plant (PLTB) is a renewable energysource that is increasingly popular throughout theworld as a solution to reduce dependen ceonfossil fuel sand reduce green house gas emissions.Abundantandrenewable wind

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energy makes PLTB anattractive option to meetin creasing global energy needs. However, the operational efficiency andreliability of PLT Bisvery dependent on a monitoring system that is able to monitor turbine performance in real-time [10] .

An effective electrical power monitoring system is needed to ensure that wind turbin esoperateat optimal conditionsand to detect early potential problems that could cause 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. Arduino Uno is a flexible and popular microcontroller platform, which can be used to develop various monitoring applications with low cost and minimal complexity [11] .

Arduino Unoisequipped with various features that enable thein tegration of sensors to measureim portantparameters such as wind speed, voltage, current and frequency of power output from a wind turbine. Data obtained from these sensors can be processed and analyzed to provideaccurate andreal-time information regarding PLTB operational conditions.In addition, the wireless communication capabilities of the Arduino Uno allow sending data to other devices for remote monitoring, so that operators can take necessary actions quickly and efficiently [12] .

Implementation of an Arduino Uno-based monitoring system in PLTB has the potential to increase operational efficiency and reduce maintenance costs by detecting anomalies and predicting failures before they occur. Case studies carried out on various wind turbine models show that the sesystem sarecapable of providing reliable and consistent performance, and canbe adapted to meet the specific needs of various types of geothermal power plants [12] .

This research aimstodevelop andanalyze anelectrical power monitoring system for aPLTB based on ArduinoUno, with a focus on sensor integration, data collection and processing, and system performance analysis. It is hoped that the results of this research can make a significant contribution to the development of smarter and more efficient monitoring technology for PLTB, as well as support global efforts to increase the use of renewable energy .

2. DEFINITION OF WIND POWER PLAN

2.1 Understanding Wind Energy

Several researchers have conducted research related to wind turbines, including: Bambang Setioko, Theincreasein fuel prices encourages people to look for new alternatives that are cheap and easy to obtain, so that they can be used for exploration and usedas the main driver for electricity generators to supply electricity. Procedures for handling and checking information in the context of assembling wind turbine aremadeby taking informationon the number offans, spotsize, wind speed and number of shocks.Relapse screening isused asa strategy toestablisha practicalrelationshipbetween twofactors, especially independent and subordinate factors [13] .

For certain wind power and speed, the range, size, height and rotational speed of the rotor can be known.The rotor area is significantly affected by the power coefficient. The design rotor rotational speed can be determined after the rotor width is determined andthetip speedis not completely determined.This studyusesa widthto average proportionof0.1;0.8 ;0.8.The result isatableof force, windspeed, rotor area, density, height androtational speedwhich can be used as abasisfor planning wind turbines [14] .

Windismovingair causedbytherotation ofthe earthand also due to differen cesinsur rounding airpressure. Windmoves from high air pressur etolowair pressure. When heated, airexpands. Airthathas expanded become sligh tersoitrises.Whenthis happens, the air pressure drops because thereislessair. The cold air around it flow sintothelow pressure area.Theair shrinks and becomesheavierand fall stothe ground. Abovethe ground the air becomeshota gain andrisesagain.Thisflowofrisinghot air and falling cold air is due to convection [14]

Wind power refersto the collection of useful energy from thewind. In 2005, the energy capacity of windpower generators was 58,982MW,resultinginlessthan1% of world electricity users. Al thoughstillaminor sourceof electricalenergyinmost countries, wind power generation morethanquadrupled between 1999 and 2005. Most modern wind power is generatedin the form of electricity by converting the rotation of turbin ebladesin to electric current using electric generators.In wind mills,wind energyis usedto rotate mechanical equipment to perform physical work, such as grinding or pumping water.

2.2 Wind Energy Potentialin Indonesia

Based on Government Regulation no. 79 of 2014 concerning National Energy Policy, Indonesia sets a target to achieve a new and renewable energy mix of 23% in 2025 and 31% in 2050. The target capacity for wind power plants (PLT-Wind) in 2025 is 255 MW. However, until 2020, the installed capacity of PLT-Bayu has only reached around 135 MW, with details of 75 MW in Sidrap and 60 MW in Janeponto. This shows that the development of wind energy in Indonesia still faces big challenges to achieve this national target [15] , [4] .

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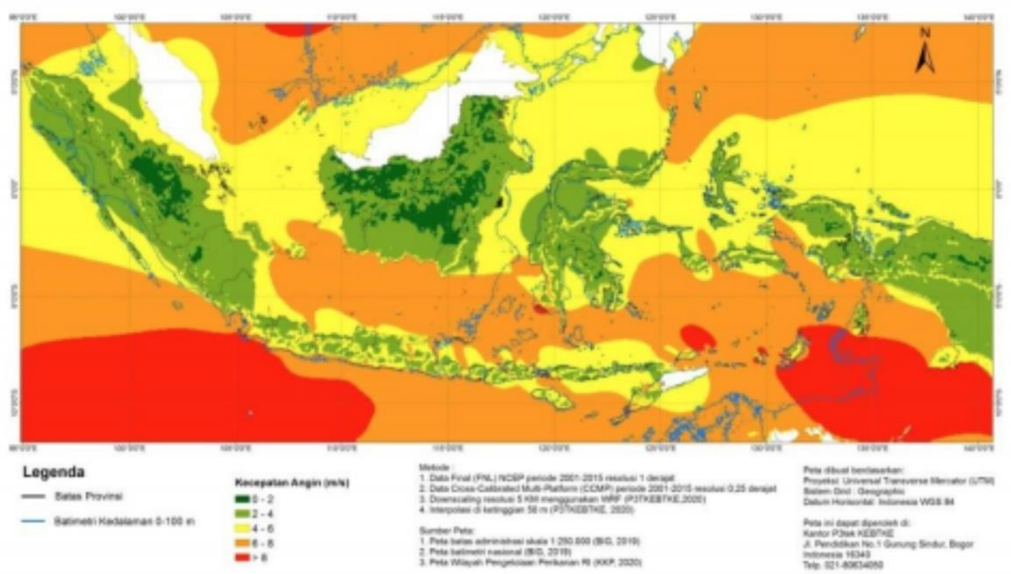

Figure 1: Mapof Wind Distributionin Indonesia

The availability of accurate wind energy potential maps through out Indonesia is very necessarya safirst stepini dentifying and selecting locations for wind energy projects. This map provides important information regarding wind characteristics in various regions, such as average wind speed, as well as maximum and minimum speeds which can be converted into power density maps and annual energy maps (in kWh or W/m²). This information is very useful as a basis for determining project locations and selecting appropriate turbine technology [16] , [17] .

Base don't heresults of wind Speed distribution mapping, it was found that high wind speeds (6 -8m/s) intheonshorearea occurred on the southern coast of Java, South Sulawesi, Maluku and East Nusa Tenggara (NTT). Meanwhile, in the off shore area, wind speed sof morethan 8 m/s weredetectedat Off shore Banten, Off shore Sukabumi, Off shore Kupang, Off shore Pulau Wetar, Off shore Jeneponto Regency, andOffshoreTanimbarIslandsRegency. Maximumwindspeedsoccur inJune, Julyand August (JJA) during the Australian monsoon season, while minimum speeds occur in March, April and May (MAM) during the transition from the Asian monsoon to the Australian monsoon [16] .

2.3 Typesof Wind Turbines

A wind turbine is awind millused to generate power. This wind turbine was originally created to meet thene eds off armers inprocessing rice, water management needs, andsoon. Many wind turbine sof the pastimplied Denmark, the Netherland sand other European countries and werealso called Wind mills, including the Horizontal Axis wind turbine (TASH) having aprimary rotor shaf tandan electric generator atthehighest point of the peak. Small turbine sare coordinated by direct wind vanes (climate vanes), while large turbines generally use wind sensors combined with servo machines. Mostof them havea box. Wind turbines have several types including: gears that change the slow wheel shaft to a faster one [18] .

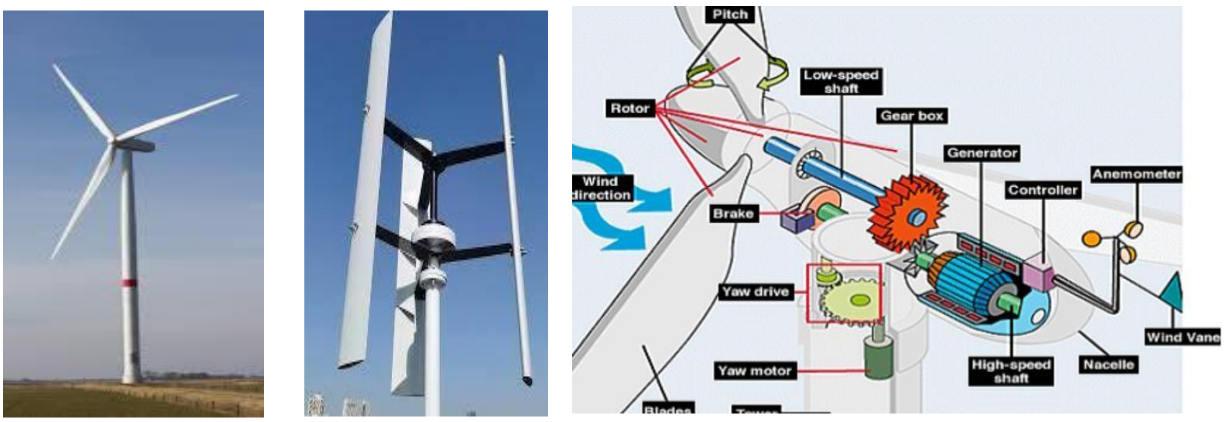

Figure 2. Wind Turbine andWind Turbine Components

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2.4 Arduino Uno

Arduino Uno isaboard that uses the ATmega328 microcontroller. The Arduino Uno has 14 digital pins (6 pin scanbeused as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a voltage sour ceconnector, an ICSP header, and a reset button. Arduino Uno contains everything needed to support a microcontroller. Just by connecting it to a computer via USB or providingDC voltage from a battery or AC to DC adapter can make it work. Arduino Uno uses an ATmega16U2 which is programmed as a USB to serial converter for serial communication to a computer via a USB port [12] .

Arduino Uno isavery popular microcontroller andisoftenusedin electronic sproject sandembedded systems. Theworking principle of the Arduino Uno involves processing digital and analog signals to control various hardware devices through programming written in the Arduino Integrated Development Environment (IDE). The following is an explanation of the working principle of Arduino Uno [12] .

Basic Structure Arduino Uno consistsof several main components:

- ATmega328P Microcontroller: This is the core of the Arduino Uno which is responsible for running the up loaded programs.
- Digital and Analog Pins: Arduino Uno has 14 digital I/O pins and 6 analog input pins which are used to read signals from sensors or control actuators.
- VoltageRegulator:Ensuresthat the micro controller and other component sgetastable voltage.
- USB Connection: Used to upload programs from the computer to the microcontroller and can also beused to provide power to the board.
- Memory: The ATmega328P has flash memory for storing programs, SRAM for temporary data, and EEPROM forlong-term data storage.

Working Principle Steps

- Program Writing: Program sarewrittenin Arduino programming language which is similar to C/C++ in Arduino IDE.
- Program Compilation: The written program is compiled in the Arduino IDE into binary code that can be understood by the ATmega328P microcontroller.
- Program Upload:Thebinarycode is uploadedto the microcontroller'sflash memoryvia aUSB connection using the integrated bootloader protocol.
- Program Execution: Once uploaded, the microcontroller immediately executes the program that has been uploaded. This program can be a loop that continues to run as long as the Arduino is powered.
- Input and Output Processing: The microcontroller reads input from digital and analog pins, processes the data according to program logic, and produces appropriate output via digital or PWM (Pulse Width Modulation) pins.
- Interaction with Hardware: Arduino Uno can interact with various hardware such as sensors, motors, LEDs, and communication modules. For example, a temperature sensor can provide analog input to a microcontroller, which is then processed to control fan speed via a PWM output.

Arduino Uno works by reading input from sensor soro ther devices, processing the input according to theuploaded program, andproducing output thatcontrol sother devices. With it simple structure and flexible programming capabilities, the Arduino Uno is a very useful tool in the development of electronic and automation systems.

Figure 3. Arduino Uno, Current Sensorand Voltage Sensor

2.5 Current Sensor

A current sensor is a device used to measure theflow of electric current in a circuit. Current measurement is importantfor a variety of applications, including power monitoring, electrical system protection, and measuring the efficiency of electronic devices. Current sensors work by converting the electric current passing through them into a voltage or digital signal that can be measured and analyzed. Current sensors play an important role in a variety of electronic and electrical applications by providing an accurate andreliable wayto measurecurrent. Understanding the

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working principles and types of current sensors available helps in selecting the right sensor for a particular application, ensuring accurate measurements and optimal system protection [19] [20] .

2.6 Sensor PZEM-0042.7

PZEM-004T isasensor that can beused to measurerms voltage, rms current and active power which can beconnected via Arduino or otheropen sour ceplat forms. The physical dimension sof the PZEM-004T boardare 3.1 ×7.4cm. Thepzem-004t

Module is bundled with a 3 mm diameter current transformer coil which can beused to measurea maximum current of 100A .

3. RESEARCH METHODOLOGY

A system flowchart isa diagram that explains program flow starting from start to finish 1 processor 1 work cycle. In this case, System Flowchart work begins with initialization and initial values. After that the system will startdoarrangement connection WiFi, Arrangement connection WiFi will starts with connect module ESP-01 to SSID Which has registered,If ESP 8266 does not find or connect to the SSID, then the system will keep trying to connect the system by SSID until it connects. After connected, then the system will start reading the voltage and current sensors and processing them data from sensors become mark whichcan unders tood by users. Markthe will be displayed on the LCD and sent to the thing speak server via an etwork connection WiFi Which has connected.

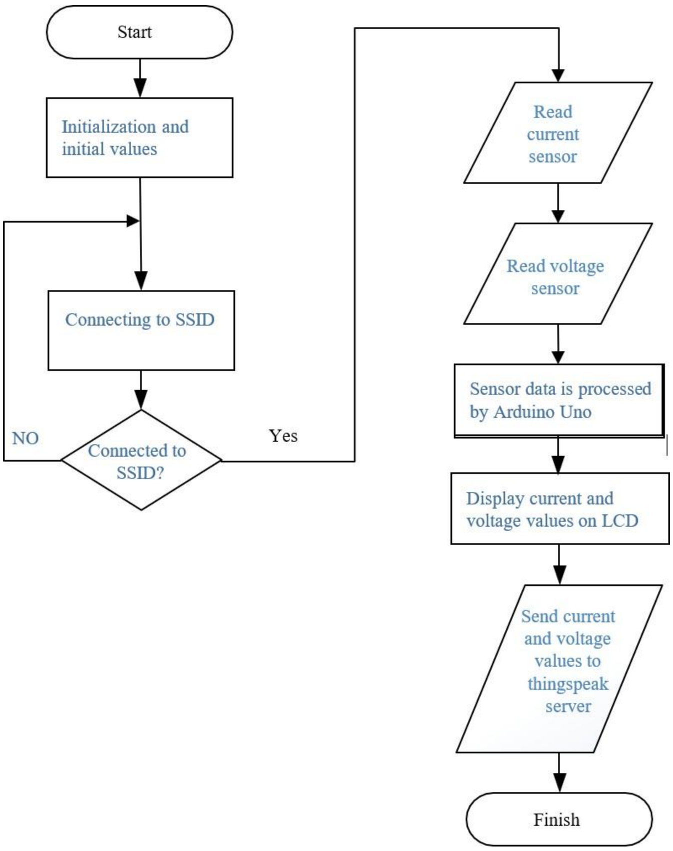

Figure 4. Research Flow Diagram

The equation usedin this research is:

$$V_{out}=V_{in}x(R_1/(R_1+R_2)) \quad (1)$$

$$I=V/R \quad (2)$$

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4. RESULTS

Results Study is anlisa from implementation study Which has carried out, there searchresultsare in the formofaproto type model of the turbine monitoring system angina which consists of a5blade wind turbine, charge controller, battery and monitoring system.The wind turbine blades will rotateif some thing blow stowards them wind turbine, the blades will rotatethe generator contained in the wind turbine will produce an electric voltage which is then output from that voltage will be connected to the charge controller using a cable. Charge controller will controls the electrical power from the wind turbine to keep it stable to rechargethe battery even though the electrical power produced by the wind turbine is not stable and fun ctionalas safety sothat voltage battery No flow to generator turbine wind when the wind turbine does not produceany electrical power at all.

Monitoring systemconsists of analog and digital electronic circuits. The system consists of a power supply,current sensor, voltage sensor, Arduino microcontroller, ESP-01 chip, LCD. Thes ystem consists of 2AC712 current sensors, each measuring current The charge controlleris actively recharging the battery and measuring the output current battery when aloa disinstalled. To measure battery voltage, a circuit is used divider voltage. Arduinouno Also control delivery data to LCD fordis plays there sults of current and voltage sensor readings. The ESP-01 chip work sonregion Which relate with delivery data via wifi, data results measurement.

4.1 Current Sensor Test Results

Censorship current ACS712 Work basedon technology Hall effect. Onsensors This thereis Suite low-offset linear Hall with One trajectory which is made of copper. The way this sensor works is that theread current flows throught hecop percable contained inside which produces a field magnet which in catch by integrated Hall I.C. Genre current electricity Which result Medan magnet Which induce part *dynamic offset cancellation* from ACS712, part This will strengthened by *amplifiers* And through *filters* Which convertedin to proportional voltage. For measurecurrent Which pass sensors This used formula voltage at pin Out=2.5±(0.185xI) Volts, whereI=current detectedin Ampereunits. Testing to find out what the sensoris working and functioning properly can bedone by providing a power supply supply on sensors Then sensors given variation burden resistor

Table 1: Current SensorTest Results

No	Markresistor(ohms)	Voltage source (volt)	Current calculation (amperes)	Markreading sensor (amperage)	%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

4.2 Testing Suite Divider Voltage

Voltage Dividers or Divider Voltage is something Suite simplemethod that converts a large voltage into a smaller voltage. The Voltage Divider Rule is that the input voltage is divided proportionally according to the resistance value of two resistors connec tedinseries. Testing Suite divider voltage with give supply Power on Suitedivider voltage. Mark voltage on output output connected to the positive probe of the multimeter and the negative probe of the multimeter connected to power supply ground or ground and divider circuit ground voltage. The voltage value at the output of the voltage divider circuit also read byArduino and displayed on the serial monitor. Here are the results testing voltage divider circuit.

Table 2:Voltage Divider Circuit Test Results

No	Reading Multimeter (volts)	Outputs Arduino (volts)	%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

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4.3 Testing Cat Power or Regulators

The power supply usedisa 12 VDC VRLA battery. Regulators LM2596 regulator is used to provide constant voltage supply 5 volt on series system Andsensors. Testing done with give supply input Anduse multimeter For measure input voltage and output voltage in both circuits. Supply voltage input comes from a 12 volt DC battery

Table 3: Power Supply and Regulator Test Results

Condition	Inputs VCC (volt)	LM 2596 outputs (5 volt)
Without Burden	12,10	5.00
With Burden	11.80	4.99

4.4 Conclusion

This research has provided in-depth insight into the theory and working principles of various types of current sensors, including shunt resistors, Hall effect sensors, current transformers (CT), and optical current sensors. Each typeof sensor has a unique working principle and different advantagesand disadvantages, which affect their application in various situations. This research focus esthat selecting theri ghttype of current sensor is very important and must bebased on thes pecificneeds of the application. Current sensors have animportan trolein power monitoring, electrical system protection, efficiency measurement, and battery charging. By understanding the working principles of each sensor, wecan optimize their use for various electronic and electrical applications. Proper implementation of current sensors not only improves measurement accuracy, but also improves overall system reliability and efficiency. This research also shows the importance of sensor calibration and maintenance to ensure optimal performance. As a crucial tool in various industries, effective and reliable current sensors can help in developing smarter and more sustainable energy solutions.

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Wehopethat the results of this research can make asignificant contribution to the field of flow monitoring system development and can become a basis for further research.

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