Yawing based IoT Monitoring System to Improve Horizontal Axis Wind Turbine Performance

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***Abstract*— The diminishing availability of non-renewable energy resources such as coal, oil, and natural gas has prompted efforts to seek sustainable energy alternatives. One promising alternative is wind energy, which can be converted into electricity through wind turbines. However, Horizontal Axis Wind Turbines (HAWTs) have limitations in capturing wind from various directions, affecting operational efficiency. Therefore, this research attempts to address this issue through an innovation in yawing-based monitoring systems integrated with HAWTs and Internet of Things (IoT) technology. The yawing-based monitoring system is designed to monitor the performance of HAWTs in real time, including wind speed, rotations per minute (rpm), electrical current, and voltage. Data obtained from this monitoring system is used to identify potential damage to HAWTs, enabling timely preventive measures. Furthermore, this monitoring system can enhance the operational efficiency of HAWTs, reduce maintenance costs, and extend their lifespan. The results obtained from the comparison between the conventional system and the system with active yawing show a significant increase in power generated by the turbines equipped with the active yawing system. On average, turbines with the conventional system produce 213 watts of power, while turbines equipped with the active yawing system reach a power output of 296 watts. This represents a 39% increase in turbine efficiency, enhancing wind energy capture efficiency. These findings confirm that the integration of the active yawing system can optimally align the turbines with the incoming wind direction, thereby improving the overall system performance.**

Keywords*— *HAWT, IoT, renewable energy, yawing.

I. INTRODUCTION

Energy resources are a part of natural resources that provide the energy needed by humans. One of the energy needs that continues to increase is electricity. As time progresses, the use of renewable energy sources has become an alternative for meeting the electricity supply needs. This is due to the depletion of non-renewable energy sources such as coal, oil, and natural gas each year. According to the official website of Bappenas, as of 2020, the Ministry of Energy and Mineral Resources recorded that 50.3 percent of electricity in Indonesia was generated through coal-fired steam power plants [1]. This high percentage of dependence on non-renewable energy sources, specifically coal, can potentially lead to the depletion of coal reserves in the near future.

One of the renewable energy sources that can serve as an alternative for generating electricity is wind energy. Wind energy has the potential to be converted into electricity using wind turbines. Wind turbines come in various types based on the axis of rotation, namely Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT). HAWT has blades connected to a horizontal axis, while VAWT has blades connected vertically. Horizontal Axis Wind Turbine (HAWT) is a renewable energy technology used to generate electricity by harnessing the kinetic energy of the wind to rotate the blade angles, thus producing electricity. Horizontal-axis wind turbines (HAWTS) represent one of the most promising renewable energy technologies, especially as the energy density increases with the recent developments in rotor size [2].To ensure the optimal operation of HAWT, a yaw system is crucial for adjusting the blade angles to constantly face the incoming wind [3]. The yaw system is designed with a rotor-upwind configuration to receive wind from the rotor or a rotor-downwind configuration to accept wind passing from behind the tower and nacelle before reaching the rotor [4]. However, there is an issue where HAWT turbines can only capture wind from two wind directions. Therefore, the use of this type of turbine may not be optimal in locations where wind direction changes frequently.

Fig. 1. Horizontal Axis Wind Turbine

In operation, a monitoring system is essential to track the performance and condition of HAWT in real-time to identify potential damage or failures in HAWT before they occur, allowing for timely preventive measures and repairs [5]. Wind speed and rpm monitoring systems can be used to determine the turbine's operational zones. Furthermore, the use of yaw systems and monitoring in HAWT provides benefits such as improving operational efficiency, reducing maintenance costs, and extending the lifespan of HAWT. This HAWT monitoring system includes data loggers for wind speed and direction, voltage, and current. In wind turbines, electrical current is generated by the rotation of the generator and is stored before being directed to the load. During this process, monitoring of electrical current, voltage, and power from the wind turbine is necessary to monitor the electrical power generated by the wind turbine (Selviyani, 2016). Therefore, this research proposes an innovative monitoring system for yawing-based HAWT integrated with an IoT platform and a website to optimize the performance of horizontal axis wind turbines. This research contributes that yawing has an average increase in power of 296 W compared to the conventional system of 213 W.

II. METHOD

A. Stage of Creating the Hardware Prototype for the Efficient Turbine

The first stage in the development of this efficient turbine system is the creation of an efficient hardware system design. During this phase, the research team collaborates to produce an accurate and efficient circuit schematic. This schematic includes various components such as sensors, microcontrollers, and stepper motors as actuators. The schematic is then simulated to ensure that the design functions properly and meets the specified efficiency goals. Following successful verification of the circuit schematic through simulation, the next step is to transform this schematic into an actual printed circuit board (PCB). This process involves transitioning the schematic from a conceptual form into a physical format that can be manufactured and implemented. To accomplish this, the team uses customized Eagle software to match the components used in this project.

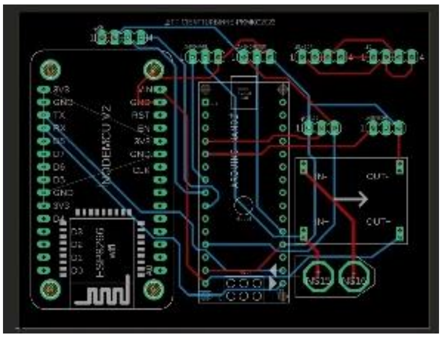

Fig. 2. Schematic Design of PCB

The creation of the efficient turbine prototype is then carried out in the Instrumentation and Control Laboratory of the Electrical Engineering Department at Universitas Sebelas Maret. This laboratory is a crucial facility in the development of this project because it provides the necessary resources and equipment for building, testing, and optimizing the turbine prototype.

B. Stage of Creating the Website Prototype for the Efficient Turbine

The software development phase begins with the team creating pseudocode and outlining the data transmission process from the sensors to ensure data can be displayed. The objective of developing this software is to establish a database for storing sensor data. Subsequently, the process involves creating a website interface capable of displaying real-time sensor data. The development of the efficient turbine prototype is carried out in the Instrumentation and Control Laboratory of the Electrical Engineering Department at Universitas Sebelas Maret.

1) Creating the Website Frontend

In the software development phase, the team begins by creating pseudocode and outlining the data transmission flow from the sensors to ensure that the data can be displayed. The purpose of developing this software is to establish a database for storing sensor data. Subsequently, the process involves creating a website interface capable of displaying real-time sensor data. The development of this website utilizes the Bootstrap framework, which incorporates HTML, CSS, and JavaScript.

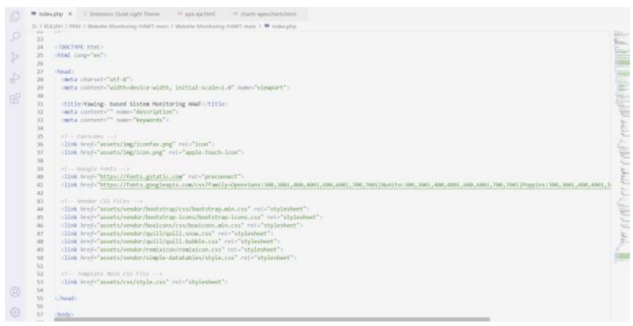

Fig. 3. Frontend Website using VS Code Software

2) Creating the Website Backend

In this process, a database is created to serve as the server using Firebase Realtime Database. Subsequently, the initialization of the server address is performed to obtain and store each change in JSON data, which includes current, voltage, power, wind speed, angle, and the date of data entry. This Firebase Realtime Database is initialized within the website using the JavaScript language.

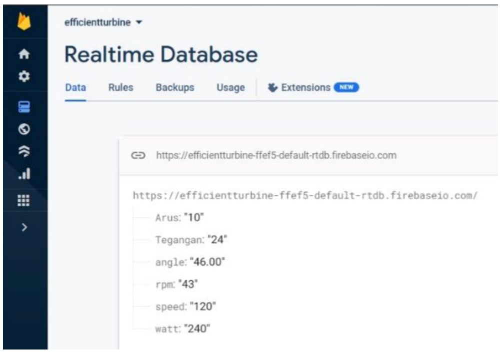

Fig. 4. Backend using Firebase Realtime Database

Fig. 5. Efficinet Turbine Website

C. *Assembly Phase of the Yawing System*

In this phase, the primary focus is to integrate the active yawing system into the turbine structure and connect it to the generator system to optimize wind energy capture. Yaw mechanism is used to orientate the wind turbine rotors against the wind direction. The orientation of the turbine is controlled by applying the wind direction from the wind wane as directional set point (ZAFAR, 2018). This process ensures that the turbine can accurately orient its blades in the direction of the incoming wind, thereby maximizing energy capture efficiency.

In the assembly of the active yawing system, the main driving component in controlling the yawing or horizontal movement of the turbine is the stepper motor. The stepper motor is programmed to respond to real-time changes in wind direction, enabling the turbine to continuously face the optimal direction for efficient wind energy capture. In addition to the stepper motor, a wind vane sensor is also used to monitor wind direction, and a power sensor provides input to the stepper motor control system. The design of optimized yaw controls has been addressed in several studies, like (Song, D.; Fan, X.; Yang, J.; Liu, A.; Chen, S.; Jo, 2018) (Karakasis, N.; Mesemanolis, A.; Nalmpantis, T.; Ma, 2016) (Shariatpanah, Fadaeinedjad, & Rashidinejad, 2013) (Song, et al., 2018) (Saenz-Aguirre, Zulueta, Fernandez-Gamiz, Lozano, & Lopez-Guede, Artificial Neural Network Based Reinforcement Learning for Wind Turbine Yaw Control, 2019) (Saenz-Aguirre, Zulueta, Fernandez-Gamiz, Ulazia, & Teso-Fz-Betono, Performance enhancement of the artificial neural network–based reinforcement learning for wind turbine yaw control, 2019).

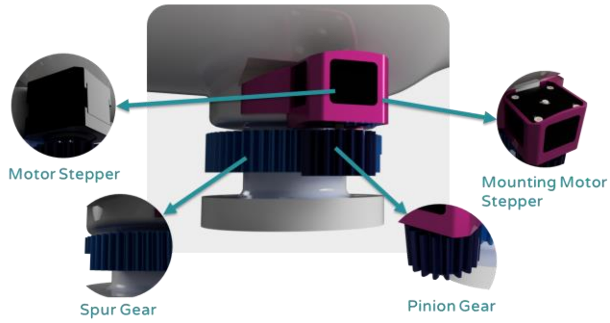

Fig. 6. Yawing based System

During this assembly process, the precision of the active yawing system is of utmost importance, as any inaccuracies in aligning the turbine can reduce the overall system's performance. As for yaw control, its primary goals are to make the turbine rotor always face the wind to increase power, reduce the loads induced by the yaw misalignment. (jian Yang, et al., 2020) Furthermore, thorough testing is required to ensure that all components function properly and collaborate effectively with each other.

III. Result and Discussion

The use of these sensors enables the team to accurately and comprehensively monitor the turbine's performance over a specific period. Additionally, the data collected at this stage serves as the foundation for benchmarking methods. In the benchmarking approach, data from turbines equipped with an active yawing system is compared to data from turbines that do not utilize yawing systems. The purpose of this is to evaluate the extent to which the active yawing system enhances performance in terms of wind energy capture efficiency.

Moreover, these sensor readings are used as a reference for the movement of the stepper motor, which results in braking or reducing wind intake during power overcapacity (overwatt) conditions. This helps mitigate the risk of damage to the modules and the generator.

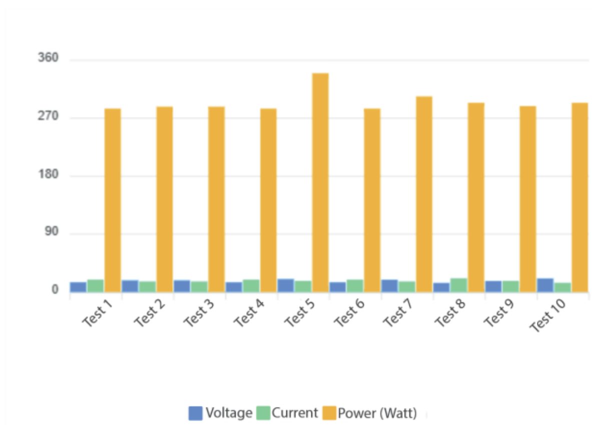

Fig. 7. Conventional System Power Data

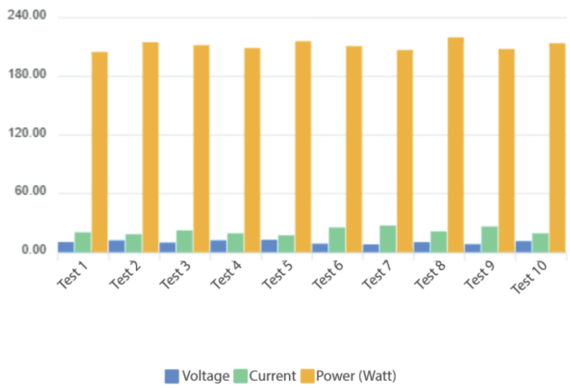

Fig. 8. Yawing System Power Data

The results obtained from the comparison between the conventional system and the system with active yawing show a significant increase in power generated by the turbines equipped with the active yawing system. On average, turbines with the conventional system produce 213 watts of power, while turbines equipped with the active yawing system reach a power output of 296 watts. This represents a 39% increase in turbine efficiency, enhancing wind energy capture efficiency. These findings confirm that the integration of the active yawing system can optimally align the turbines with the incoming wind direction, thereby improving the overall system performance. A higher energy capture can be achieved by increasing the yaw control sensitivity. This means the yaw system rotates the nacelle based on a smaller yaw error threshold and on the foundation of shorter averaged measured times of the wind direction and speed (M-G Kim & P H Dalhoff, 2014).

IV. Conclusion

Based on the data collection and benchmarking against the system without yawing, the conclusion is drawn tha based on the test results, the Yawing Based Monitoring prototype, based on IoT for horizontal axis wind turbines, improves effectiveness by 38% compared to the conventional. The Efficient turbine is capable of handling overvoltage conditions in the generator.

Acknowledgment

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