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Early Fault detection in the main bearing of wind turbines based on Wireless sensor network

SaravanaKumar M[1], Santhosh R[2], Sasi Prakash P[3], Dr. D. Selvaraj, M.E., Ph.D.,[4]
[1,2,3]Department of Electronics and Communication Engineering, Panimalar Engineering College, Chennai – 600012
[4]Professor, Department of Electronics and Communication Engineering, Panimalar Engineering College Chennai – 600012
Email ID: *saravana994182@gmail.com[1], sandygeetha9@gmail.com[2], sasiprakash3108@gmail.com[3], drdselvaraj@panimalar.ac.in[4]*

Abstract

Wind turbines are highly important in the field of renewable energy production, but the unforeseen breakdowns of components especially in the main bearings may cost a lot of downtime and money. The paper suggests a real-time fault detection system of wind turbine primary bearings with the help of a Wireless Sensor Network (WSN) with an embedded monitoring system. This system comprises of voltage, current, and temperature sensors as well as Arduino ATmega328 microcontroller to acquire and process real-time data. Following a controlled power supply is a steady operation of the system and the measured parameters are indicated on an LCD on-site and sent wirelessly to a remote monitoring device. A detection system is introduced that is based on a threshold to detect abnormal operating conditions including over current and excessive temperature increase. Experimental validation shows that the system is able to identify faults in real time, and produces early warning signals before the system breaks down in a critical state. This method is both economical, easy to apply and applies in a real world situation in health monitoring of wind turbines.

Keywords: *Wind turbine, Main bearing fault detection, Wireless sensor network, Condition monitoring, Arduino.*

1. Introduction

The interrelated world has been fueled by renewable sources of energy. Another source of renewable energy is wind turbines since they make use of the power of wind to produce electricity without polluting the environment with harmful gases and greenhouse gases. This causes them to be a clean and sustainable alternative to conventional fossil fuels, which are a major cause of climatic change and air pollution. Due to this reason, wind turbines are gaining popularity and consequently, their care and safety is also of great concern. To avoid any untenable interference to the system, real-time performance checking of wind turbines is necessary to ensure optimal performance as well as dependability. Various important parameters could be measured in real-time to measure the performance of a wind turbine such as power output, wind speed and direction, turbine speed, temperature and vibration of the system, environmental conditions, etc.. Sensors, data acquisition system, and advanced analytics software can be used to monitor the performance of wind turbines in real time. This helps operators to detect possible problems before they degenerate into critical problems and undertake proactive actions to ensure optimum performance and avoid downtimes. In order to detect the performance of wind turbines, Papatheou et al. employed a version of extreme functional theory that was adapted to track the performance of wind turbines based on power curves constructed on a weekly basis using real data available on wind turbines. The proposed system by Lizza.M et al was based on the use of different tools like and Universal Asynchronous Receiver/Transmitter (UART) to monitor the state of wind turbines remotely and diagnose the possible troubles regardless of the

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location globally. Akyuza et al. proposed a system to evaluate a number of parameters of wind turbines including wind speed, air temperature, battery voltage and battery current using Microsoft Azure cloud computing software. The real-time visualization is also a part of the system with the help of the Microsoft Power BI platform where the user can see the data on the web. The interlude of Ashwini et al. is an interactive embedded system that employs Wireless Sensor Network (WSN) technology to provide a reliable, trustworthy, and efficient effective connection among the various sensors in a windmill to enable one to monitor them in any environment. Bajracharya et al. utilized the wireless sensor network technology in controlling certain parameters of a wind turbine, and they have then presented numerical outcomes of their simulations. Fu et al. introduced a method of analyzing the reliability of condition monitoring network of a wind turbine blade based on wireless sensor networks. The reliability of monitoring networks is mainly evaluated in the context of two important issues, which include the reliability of sensor nodes and the reliability of communication links. [1-3]

2. Review of Literature

Detection of faults in wind turbine systems has attracted a lot of research on advanced signal processing and artificial intelligence methods to enhance reliability and minimize the cost of maintaining the turbines. Xin Zhang (2021) suggested a fault detection algorithm, which utilizes Power Flow Transfer Entropy (PFTE), to wind power integration grids with multiple terminals on the HVDC. The method identifies and finds AC three-phase-to-ground faults by evaluating variations in power flow without the need to have communication systems. Fault ride-through capability was proven to be improved by experimental results. A signal-processing-based approach to identifying open-circuit faults in grid-connected converters was proposed by Jinyu Wen (2022). The algorithm calculates instantaneous current amplitudes online using a Weighted Sliding Hilbert Transform (WSHT) algorithm and is useful in detecting converter faults. Jinfeng Gao (2023) came up with a gearbox fault detection model using the Dilated Convolutional Neural Networks (DCNN). The dilated structure enhances the receptive field, enabling faster and more accurate real-time monitoring compared to conventional CNNs. Zhenze Jiang (2022) proposed an unsupervised acoustic-based fault detection framework using Bi-LSTM and self-attention mechanisms combined with ensemble learning. The model effectively detects early-stage abnormalities using real wind farm data. Although these approaches achieve high accuracy, many require complex computation and large datasets. Therefore, a cost-effective, real-time embedded monitoring approach for early fault detection remains essential.

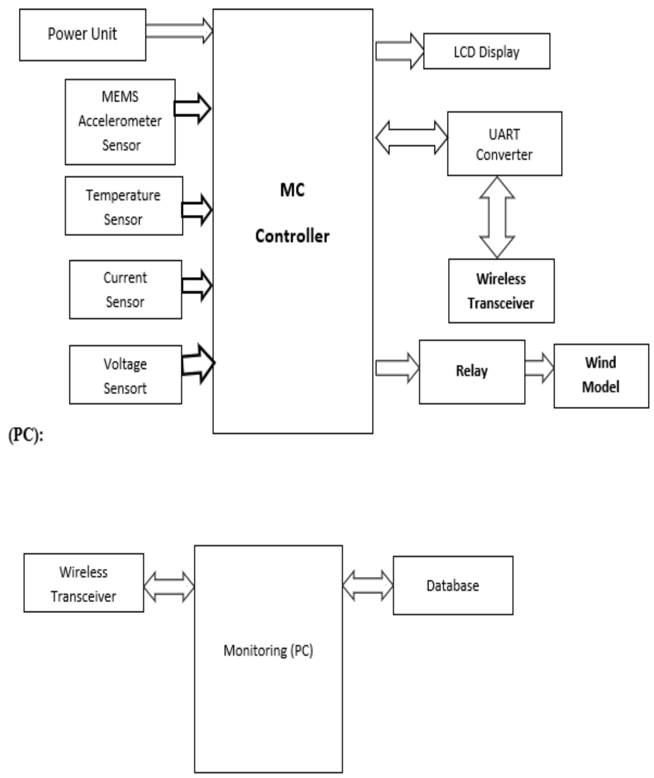

Figure 1 SBlock Diagram of the Proposed Wireless Sensor Network-Based Wind Turbine Monitoring System

3. Proposed System

This system will be used to monitor the distribution wind parameter online and will be capable of availing useful Information regarding the wind health that will guide the utilities to maximize on the use of the wind and maintain the asset in operation over a long period. Three sensors were monitored in this system, which includes voltage sensor, a current sensor and

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temperature sensor. Microcontroller Arduino uno and wireless Module were operated with the help of a power supply. The sensors detect the data and give it in LCD display at the same time the wireless module transmits data to the user on specific address according to program. We can avoid failure should we receive unsecured information about the system we are dealing with. This is put forward a model of real-time wind monitoring system. This is subdivided into four sections- Power supply (230 v step down transformer, bridge rectifier converter and regulator), controlling, data processing and data uploading. Figure 1 shows SBlock Diagram of the Proposed Wireless Sensor Network-Based Wind Turbine Monitoring System [4-6]

4. Implementation

4.1.Hardware Implementation

The proposed wind turbine bearing monitoring system was developed using an Arduino Uno (ATmega328P) microcontroller integrated with voltage, current, temperature, and vibration sensors. A regulated 5 V DC supply was designed using a step-down transformer, bridge rectifier, filter capacitor, and 7805 voltage regulator to ensure stable operation. The sensor outputs were interfaced with the analog input pins of the microcontroller for real-time data acquisition.

4.2.Software Implementation

The system firmware was developed in embedded C/C++ using the Arduino IDE. The microcontroller continuously samples sensor data through its 10-bit ADC, performs signal scaling, and compares the measured values with predefined threshold limits. A 16×2 LCD module is used for local display of parameters. [7-10]

4.3.Wireless Communication and Fault Detection

The wireless transceiver module was connected to a remote monitoring unit by means of UART communication used to transmit real-time information such as voltage, current, temperature, vibration, and fault condition. There was implementation of fault detection by use of rule based threshold method where the deviations that exceed safe operating limits pose early warning signs and preventive maintenance is applied prior to severe bearing failure. Figure 2 shows Design Flow of the Embedded System Development Process

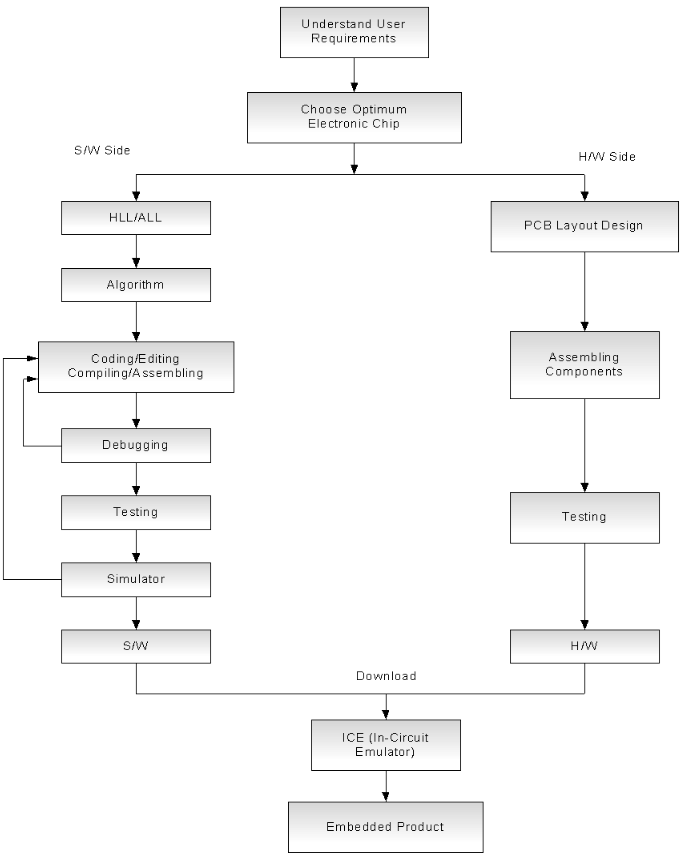

Figure 2 Design Flow of the Embedded System Development Process

5. Results and Discussion

The suggested wind turbine surveillance system using wireless sensor network was experimentally tested under laboratory simulated working conditions. Voltage, current, temperature, and vibration parameters were being continuously monitored with the system based on the integrated sensors that were connected to the Arduino ATmega328 microcontroller. The sensor data was localized on the 16×2 LCD and were also sent on-the-fly to a remote monitoring PC over a wireless transceiver module. Within the normal operating conditions, the system worked well and the voltage was well regulated by the designed power supply unit comprising of step-down transformer, bridge rectifier, filter circuit and 7805 oltage regulator. The controlled 5 V output provided consistency of the performance of the microcontroller and sensors. The system operated safely because both voltage and

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current stayed within their specified limits and no faults were detected by the system. The wireless link between the sensing node and monitoring PC maintained a constant connection which allowed successful data transfer. The testing of fault detection performance began when overload conditions were applied. The ACS712 current sensor detected an increase in current when the electrical load reached levels that exceeded its allowed limits. The microcontroller created a warning signal after checking the measured value against established threshold limits and finding that it had exceeded those limits. The LCD displayed the abnormal condition which the system sent to the monitoring system through wireless transmission. The system successfully identifies overcurrent situations which occur in actual operating conditions. Temperature monitoring was conducted to detect potential wind turbine component overheating. The temperature sensor detected abnormal conditions when it measured temperatures that exceeded the normal operating range. The system identified a fault condition when the temperature reached its preset limit and it issued an alert. The temperature monitoring system demonstrates its ability to detect early signs of component stress and bearing-related issues through its monitoring capabilities. The combination of voltage current and temperature measurement techniques provides better fault detection reliability than monitoring a single parameter. The embedded processing unit enabled immediate comparison of sensor readings with safe limits which allowed early warning before severe system failure. The experimental validation demonstrates that the proposed system delivers real-time monitoring capabilities together with dependable wireless communication and effective early fault detection for wind turbine operations. The low-cost embedded implementation makes it suitable for practical deployment in wind energy systems where continuous monitoring is essential for improving reliability and decreasing maintenance expenses. Figure 3 shows Overshoot Voltage as Vector Sum, Figure 4 shows Atmega328 (28-Pin DIP) Microcontroller Pin Diagram, Figure 5 shows Block Diagram of the Atmega328 AVR Microcontroller Architecture

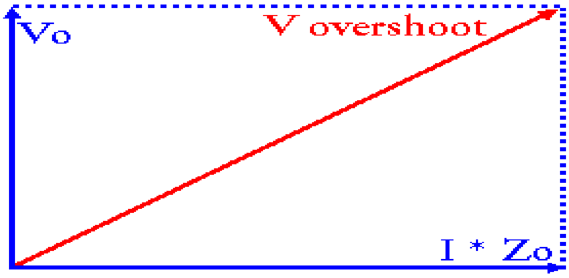

Figure 3 **Overshoot Voltage as Vector Sum**

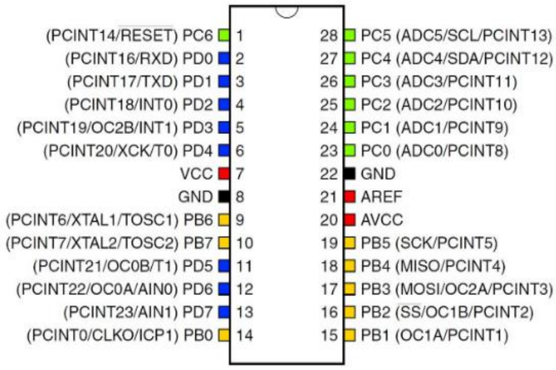

Figure 4 **Atmega328 (28-Pin DIP) Microcontroller Pin Diagram**

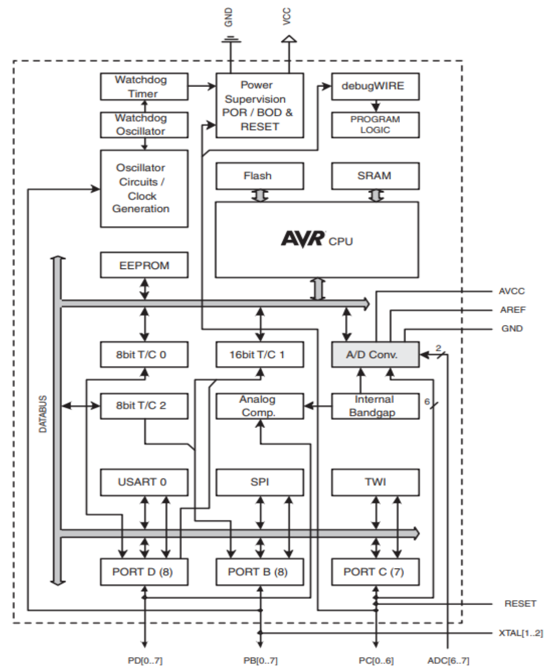

Figure 5 **Block Diagram of the Atmega328 AVR Microcontroller Architecture**

Conclusion and Future Work

The wireless sensor network monitoring system which has been developed enables real-time detection of wind turbine component failures. The system uses voltage and current and temperature sensors which work with an Arduino microcontroller to deliver precise fault detection and early warning systems through threshold-based detection methods. The system provides easy implementation at low cost which makes it ideal for real-world wind turbine monitoring needs. The future system upgrade will include vibration analysis together with advanced machine learning methods which will improve predictive fault diagnosis capabilities. The system will gain better scalability and intelligent health management capabilities when it integrates cloud-based monitoring systems together with its ability to manage multiple wind turbine networks.

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