Chapter 1

1. Introduction to the Study

1.1: Introduction

Project Topic: Affordable and Clean Energy [SDG = 7 , 13]

The diagnosis and fault monitoring of small wind turbines (SWTs) is critical for ensuring their efficient and reliable operation, especially in remote and off-grid applications. Mechanical faults, such as bearing wear, shaft misalignment, rotor imbalance, and gearbox failures, are among the most common issues that can lead to performance degradation or system breakdown. Leveraging the Internet of Things (IoT) technology, real-time monitoring and early fault detection can be achieved by integrating smart sensors with data acquisition and cloud-based analytics. This approach enables continuous tracking of key mechanical parameters—such as vibration, temperature, and rotational speed—allowing for predictive maintenance and minimizing downtime. By focusing on mechanical faults, the IoT-based diagnostic system enhances the overall lifespan and operational efficiency of small wind turbines.

Small Wind Turbines (SWTs) have gained popularity as a sustainable solution for decentralized power generation, especially in rural and off-grid areas. However, like any rotating machinery, SWTs are prone to various mechanical faults that can affect performance, increase maintenance costs, and lead to unexpected failures. Traditional maintenance methods are often reactive and inefficient, particularly in remote installations. Therefore, a modern, real-time diagnostic approach is necessary to improve the reliability and longevity of these systems. Mechanical faults in small wind turbines typically include issues such as rotor imbalance, blade deformation, shaft misalignment, gearbox failure, and bearing wear. These problems can arise from environmental stresses, material fatigue, or improper installation and can significantly reduce energy output if left undetected. Early identification of these faults is crucial for preventing catastrophic failures and ensuring continuous operation. However, manual inspection and fault detection are labour-intensive and sometimes impractical for turbines located in inaccessible areas.

The integration of Internet of Things (IoT) technology into the fault diagnosis system offers a powerful solution for remote monitoring and predictive maintenance. IoT-enabled sensors can continuously collect mechanical parameters such as vibration, temperature, and rotational speed. These sensors communicate with microcontrollers and cloud platforms to analyze data in real time, identify abnormal patterns, and trigger alerts when faults are detected. This system eliminates the need for regular manual checks and allows for data-driven decision-making .

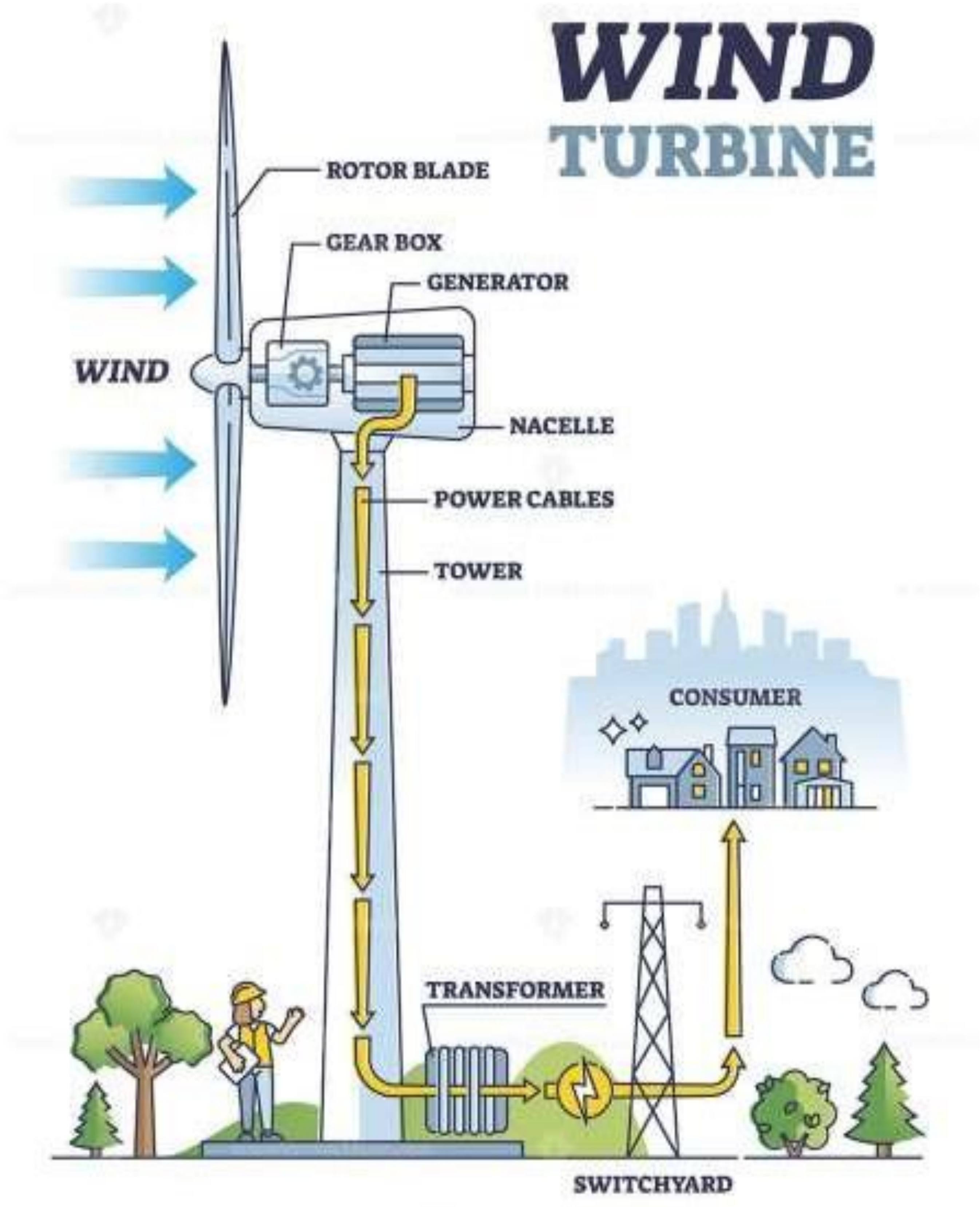

Fig 1.1 : Diagram of Small Wind Turbine

1.2 : Research Problem

The mechanical integrity of small wind turbines is critical for their reliable and efficient operation. However, traditional fault diagnosis methods often require manual inspection or are reactive in nature, leading to costly downtimes and maintenance. This research focuses on developing an IoT-based fault monitoring system specifically for diagnosing mechanical faults such as bearing wear, shaft misalignment, gear failures, and blade imbalance. The challenge lies in real-time data acquisition, effective sensor integration, and intelligent fault detection algorithms to ensure early and accurate fault identification, minimizing maintenance costs and maximizing turbine availability.

1.3 Aim and Objectives

- **Aim:**

- To design and develop real time fault monitoring system for small wind turbine utilizing Internet of Things

- **Objectives:**

- To **design** an IoT-enabled sensor network capable of continuously monitoring critical mechanical components of a small wind turbine—such as the rotor blades, shaft, and gearbox—for vibration, temperature, and rotational speed anomalies.

- To **develop** a real-time fault detection and data acquisition system that collects sensor data, transmits it via IoT protocols (e.g., MQTT or Wi-Fi), and logs it on a cloud-based dashboard for visualization and alerts.

- To **analyse** mechanical fault patterns using collected data by applying signal processing or machine learning techniques to identify early signs of wear, imbalance, or misalignment in turbine components.

1.4 : Justification of This Research

The performance and reliability of **small wind turbines (SWTs)** are heavily influenced by the mechanical health of their rotating components, including rotor blades, shafts, bearings, and gearboxes. Mechanical faults in these components can lead to efficiency losses, unexpected downtimes, and even catastrophic failures. However, small wind turbines are often installed in **remote or rural areas**, where regular physical inspection and maintenance are difficult and costly. Hence, **an intelligent, remote, and automated fault monitoring system becomes essential**.

The integration of **IoT (Internet of Things)** technology into fault monitoring provides a **cost-effective and scalable solution** for real-time data acquisition, analysis, and remote alerting. By focusing specifically on **mechanical faults**, this research addresses the most common and impactful sources of failure in small wind turbines. Early detection of mechanical abnormalities such as vibrations, misalignments, or wear can prevent severe damage, extend turbine lifespan, and reduce maintenance costs.

Furthermore, this research supports the **transition toward smart, self-diagnosing renewable energy systems**, aligning with global sustainability and digital transformation goals. It fills a critical gap in existing maintenance strategies by offering a **non-invasive, real-time, and data-driven method** to improve the reliability and efficiency of small-scale wind energy generation systems.

Thus, this study is both **technically and socially justified**, promoting reliable renewable energy while minimizing operational risks and costs through innovative IoT-enabled mechanical fault diagnostics.

Chapter 2

2. Literature Review

2.1 Introduction

The increasing adoption of small wind turbines (SWTs) in distributed and off-grid power generation has brought attention to the challenges associated with their maintenance and reliability. Mechanical faults such as blade damage, shaft misalignment, bearing wear, and gearbox failures are some of the most common issues that can significantly reduce the efficiency and lifespan of these systems. Traditional maintenance approaches are reactive and depend heavily on manual inspection, which is not always feasible for turbines installed in remote or hard-to-reach locations.

Recent research has shown a promising shift towards the integration of Internet of Things (IoT) technology for real-time fault monitoring in wind energy systems. IoT-based solutions typically include the deployment of various sensors (e.g., vibration, temperature, rotational speed), microcontrollers, and wireless data transmission modules. These systems enable continuous health monitoring and timely fault detection, which can greatly reduce downtime and maintenance costs. However, most of these studies have primarily focused on large-scale wind turbines, with limited attention given to SWTs.

Mechanical fault detection in SWTs using IoT is still an emerging area, and existing literature often lacks standardized methodologies tailored to smaller systems. Some researchers have proposed using low-cost microcontrollers like Arduino or STM32 paired with cloud-based dashboards for real-time visualization and alerts. Additionally, signal processing techniques such as FFT (Fast Fourier Transform) and machine learning models are being investigated for fault pattern recognition and predictive maintenance. These techniques help in identifying early signs of mechanical wear or failure, thereby enhancing operational safety and efficiency.

Despite these advancements, the literature reveals a clear gap in developing robust, scalable, and cost-effective IoT-based monitoring systems specifically for the mechanical components of SWTs. There is a need for focused research that not only adapts existing technologies to the constraints of small turbines but also evaluates their effectiveness in real-world operating conditions. This study aims to contribute to this evolving area by designing and analyzing an IoT-enabled mechanical fault diagnosis system customized for small wind turbines.

2.2 Literature Review

2.2.1 Paper 1 [Intelligent Monitoring and Control of Wind Turbine Prototype Using Internet of Things (IoT)] 2022

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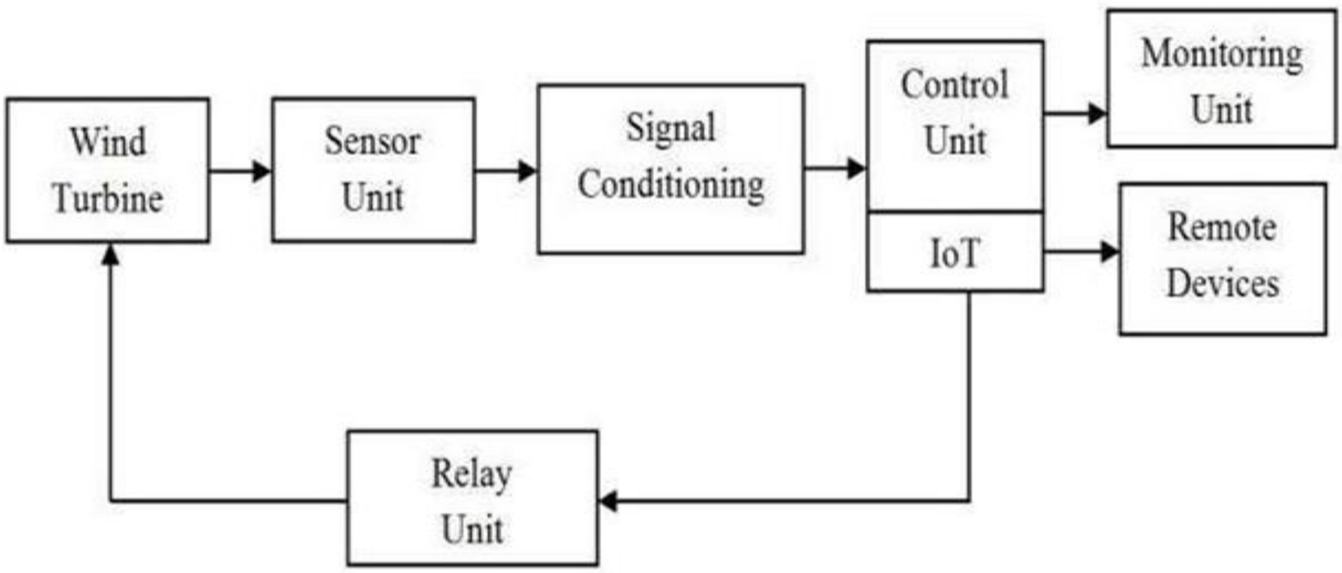

Figure. 2.2.1. Block Diagram of the Intelligent Monitoring[1]

The integration of **Internet of Things (IoT)** in wind turbine systems has significantly advanced the field of **mechanical fault detection and control**, as highlighted in several research papers. Mechanical faults such as **gearbox failure**, **bearing wear**, **shaft misalignment**, and **blade cracks** are among the most frequent and damaging issues in wind energy systems. Literature emphasizes that these mechanical faults often develop gradually and, if undetected, can lead to severe breakdowns and expensive repairs. Early detection through continuous monitoring is therefore crucial, and IoT offers an effective framework for achieving this by linking physical turbine components with intelligent data analytics platforms.

IoT-enabled wind turbine prototypes utilize various sensors—such as **vibration, acoustic, strain, and temperature sensors**—mounted on critical components to capture real-time operational data. This data is transmitted to cloud servers or edge computing units where advanced processing techniques, including **Fast Fourier Transform (FFT)**, **wavelet analysis**, and **machine learning models**, are applied to identify patterns and anomalies associated with mechanical faults. Literature surveys show that the use of such intelligent algorithms improves diagnostic accuracy.

2.2.2 Paper 2 [IOT-Enabled Fault Diagnosis and Monitoring for Small Wind Turbine] 2025

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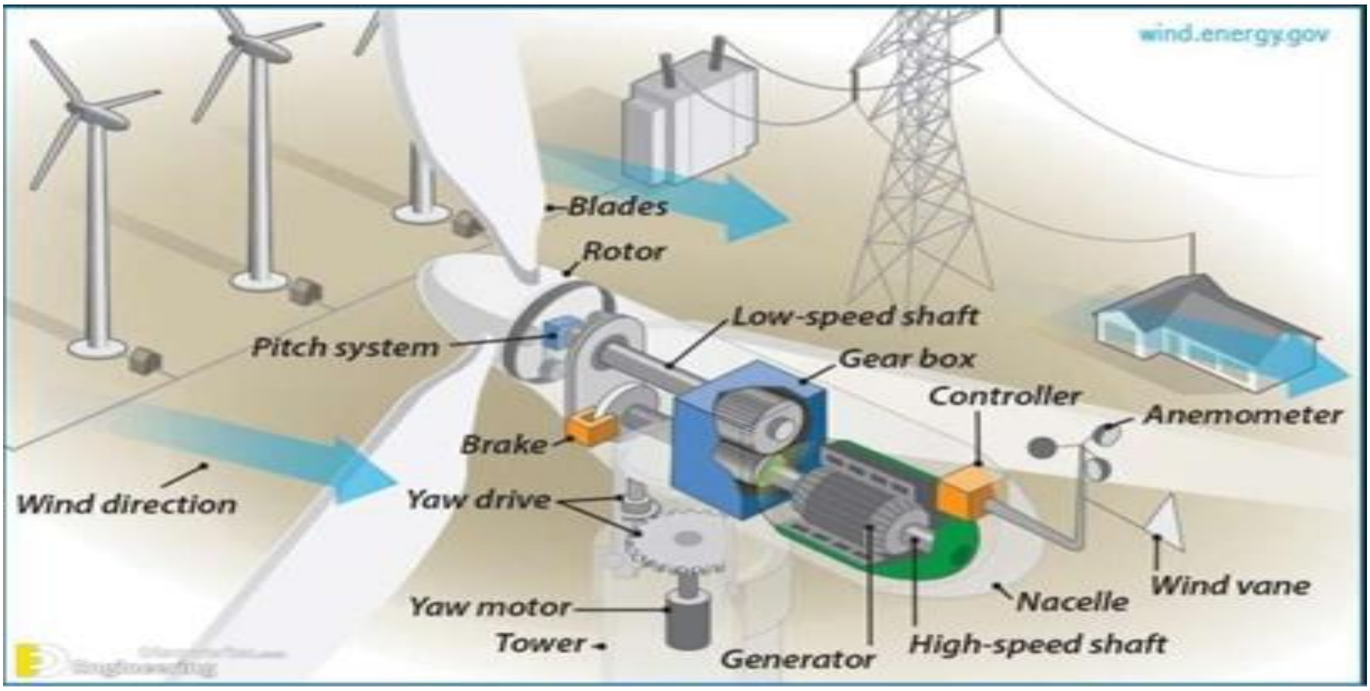

Figure. 2.2.2. Block Diagram of the IOT-Enabled Fault Diagnosis[2]

Literature on IoT-enabled fault diagnosis in small wind turbines has increasingly emphasized the importance of early detection of mechanical faults such as bearing wear, gear tooth damage, shaft misalignment, and rotor imbalance. These faults can significantly reduce turbine efficiency and lead to catastrophic failures if left unmonitored. Researchers have employed a range of sensor technologies—such as vibration sensors, acoustic sensors, and strain gauges—integrated with IoT platforms to continuously monitor mechanical parameters. This real-time data acquisition enables timely fault identification and predictive maintenance, ultimately enhancing the reliability and lifespan of small wind turbines.

Several studies have proposed advanced signal processing and machine learning algorithms for classifying and diagnosing mechanical issues based on sensor data. Time-domain and frequency-domain analysis of vibration signals are common, with features extracted and fed into models like Support Vector Machines (SVM), Artificial Neural Networks (ANN), and Decision Trees. These techniques have shown high accuracy in distinguishing between healthy and faulty mechanical states under varying operational conditions. The integration of edge computing in IoT systems further improves response time by enabling local processing of sensor data at the turbine site.

2.2.3 : Paper 3 [Fault Diagnosis and Monitoring of Small Wind Turbine] 2024

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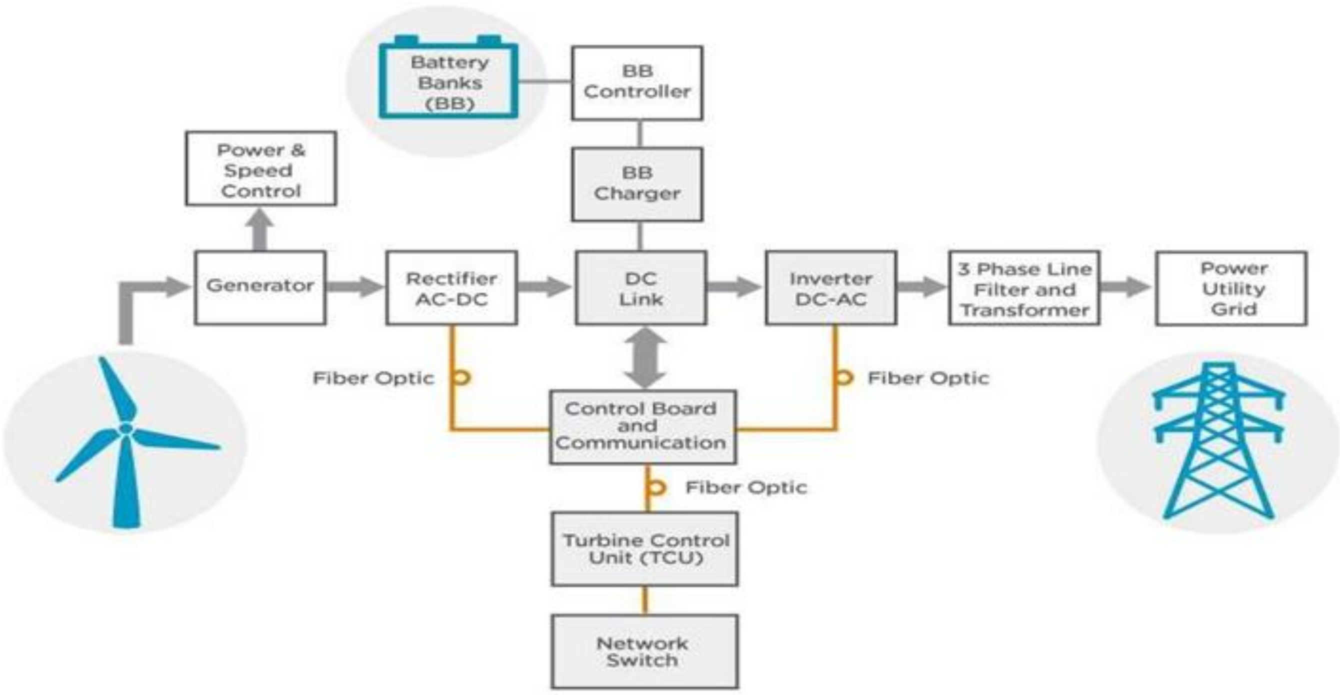

Figure. 2.2.3. Diagram of the Fault and Monitoring of Small Wind Turbine [3]

Fault diagnosis and monitoring of small wind turbines are crucial to ensuring their efficient and reliable operation, especially in remote or standalone applications. Mechanical faults are among the most common and critical issues affecting turbine performance. These faults may include bearing failures, gearbox malfunctions, rotor imbalance, misalignment, and blade defects. Such mechanical anomalies can lead to excessive vibrations, noise, energy losses, and even catastrophic failures if not detected early. To address this, various condition monitoring systems (CMS) are employed, utilizing vibration analysis, acoustic emission, and thermography to identify early signs of wear and mechanical degradation.

Advanced diagnostic techniques integrate signal processing methods with machine learning or artificial intelligence algorithms to enhance the accuracy and speed of fault detection. Real-time monitoring systems collect data from sensors mounted on key mechanical components and analyze it to detect abnormalities. Predictive maintenance strategies, supported by these diagnostic tools, help in minimizing downtime, reducing repair costs, and extending the lifespan of the turbine. In small wind turbines, where maintenance resources are often limited, implementing an effective mechanical fault diagnosis and monitoring framework is essential for maximizing energy output and operational safety.

2.2.4 : Paper 4 [Fault Diagnosis and Monitoring of Small Wind Turbine Using IOT] 2023

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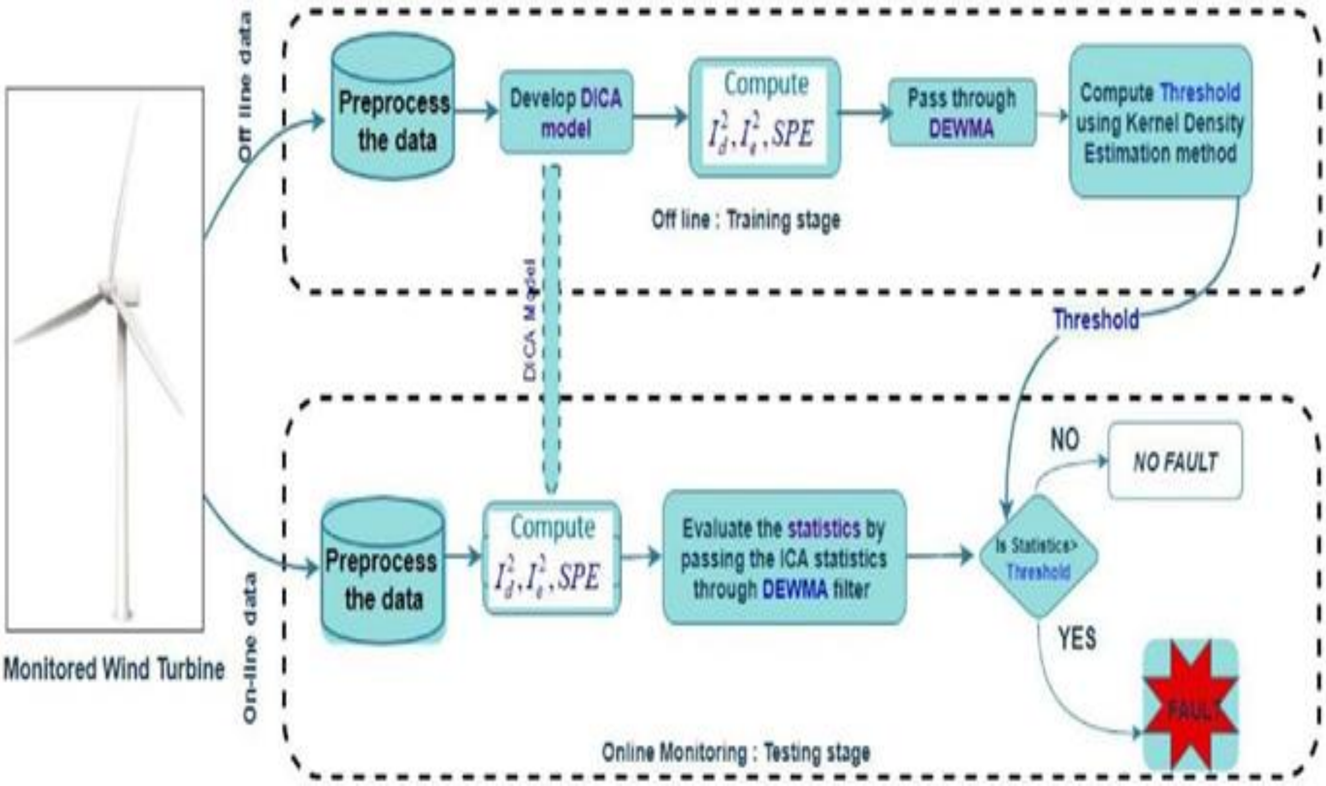

Figure. 2.2.4. Block Diagram of the Monitoring of Small Wind Turbine Using IOT[4]

Fault diagnosis and monitoring of small wind turbines using IoT (Internet of Things) technology have significantly improved the ability to detect mechanical faults in real time. By integrating IoT-enabled sensors with key mechanical components such as bearings, shafts, gearboxes, and blades, continuous data on parameters like vibration, temperature, and rotational speed can be collected and transmitted to cloud-based platforms. This real-time data monitoring allows for the early detection of issues such as misalignment, rotor imbalance, bearing wear, and gearbox faults, which are common mechanical failures in wind turbines.

With the support of cloud computing and data analytics, IoT systems can process and analyze sensor data using machine learning algorithms to predict potential mechanical failures before they occur. Alerts and diagnostics can be accessed remotely via mobile or web interfaces, enabling timely maintenance and reducing downtime. This smart, connected approach not only improves the reliability and performance of small wind turbines but also lowers maintenance costs and enhances safety, especially in remote or hard-to-access locations where traditional monitoring is challenging.

2.2.5 : Paper 5 [Fault Detection and Isolation in Wind Turbines:Type-3 Fuzzy Logic Systems and Adaptive Random Search Learning] 2024

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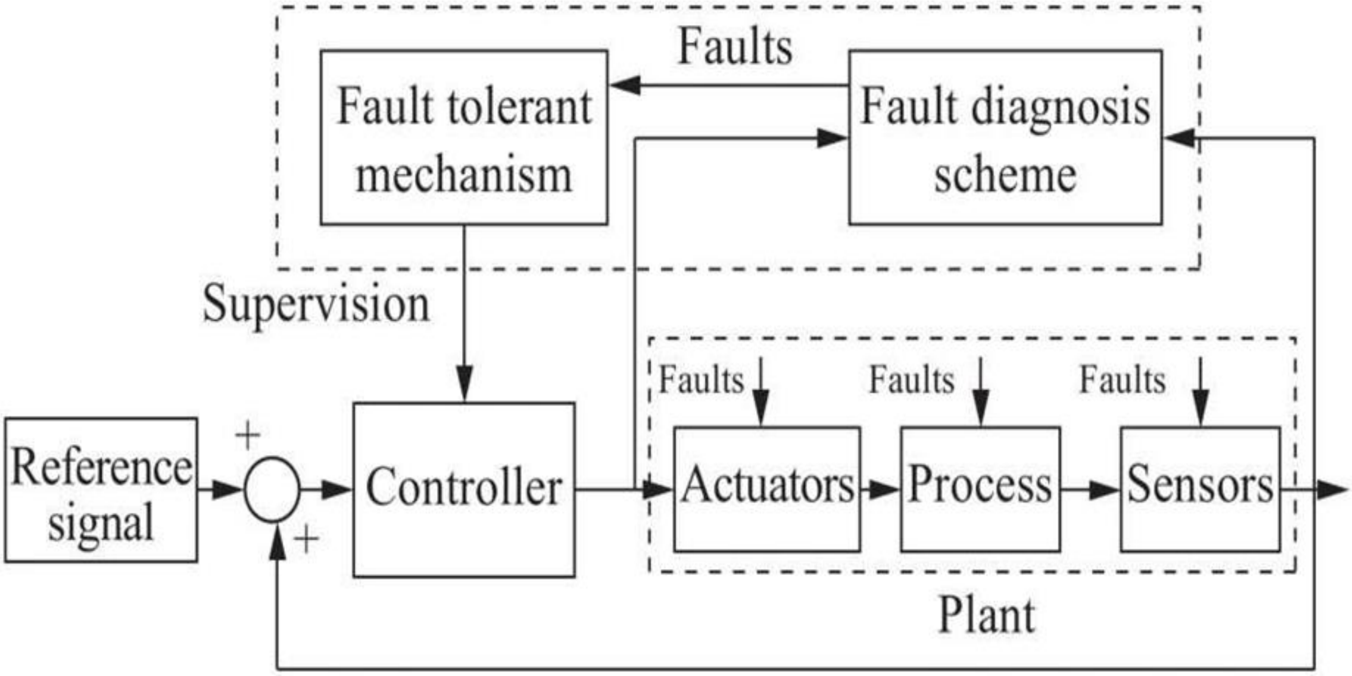

Figure. 2.2.5. Block Diagram of the Fuzzy Logic Systems[5].

The paper **"Fault Detection and Isolation in Wind Turbines: Type-3 Fuzzy Logic Systems and Adaptive Random Search Learning"** focuses on the application of advanced soft computing techniques to detect and isolate mechanical faults in wind turbines. Specifically, it addresses challenges such as gear faults, bearing wear, and unbalanced loads, which are critical to the reliable operation of wind turbine drivetrains. The study introduces **Type-3 Fuzzy Logic Systems (T3FLS)**, an enhancement over traditional Type-1 and Type-2 systems, offering improved handling of high uncertainty and noise in sensor data, which is common in wind turbine environments.

To enhance the performance of the T3FLS in fault detection, the paper proposes the use of **Adaptive Random Search (ARS) Learning**, a data-driven optimization algorithm that continuously tunes the fuzzy system parameters for better accuracy. This adaptive learning approach allows the fault detection model to evolve in real-time, improving its ability to differentiate between normal and faulty mechanical conditions. Simulation and case studies demonstrate that the integrated T3FLS-ARS system achieves higher fault classification accuracy, faster isolation, and increased robustness compared to conventional methods, making it a promising solution for predictive maintenance in wind energy systems.

2.2.6 : Paper 6 [An Early Fault Detection Framework for Wind Turbines using Vibration Signals] 2024

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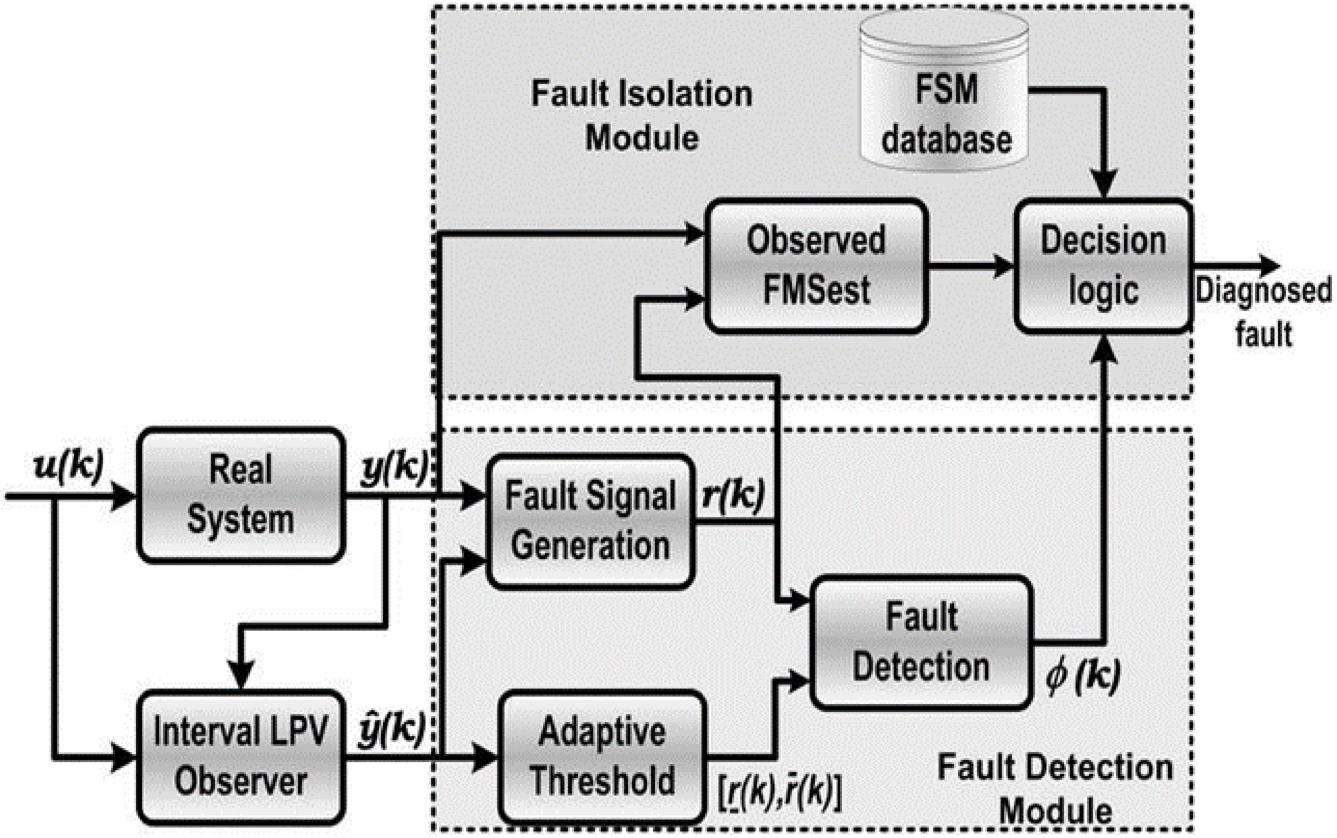

Figure. 2.2.6. Block Diagram of the An Early Fault Detection[6]

The paper **"An Early Fault Detection Framework for Wind Turbines using Vibration Signals"** presents a robust methodology focused on detecting mechanical faults in wind turbines at an early stage by analyzing vibration data. Mechanical faults such as bearing defects, gearbox damage, and shaft misalignment are critical issues that can lead to costly downtime and failures if not detected promptly. The framework leverages vibration signals as primary indicators because mechanical components typically exhibit changes in vibration patterns before visible damage occurs.

The proposed system employs advanced signal processing techniques to extract key features from the vibration data, followed by machine learning algorithms to classify the health state of the turbine components. By continuously monitoring and analyzing these signals, the framework enables early identification of abnormal behavior, allowing for timely maintenance actions. The study demonstrates that the approach significantly improves detection accuracy and reliability, offering a practical and efficient solution for condition monitoring of wind turbine mechanical systems.

2.2.7 : Paper 7 [Vibration Analysis for Fault Detection of Wind Turbine Drivetrains—A Comprehensive Investigation] 2023

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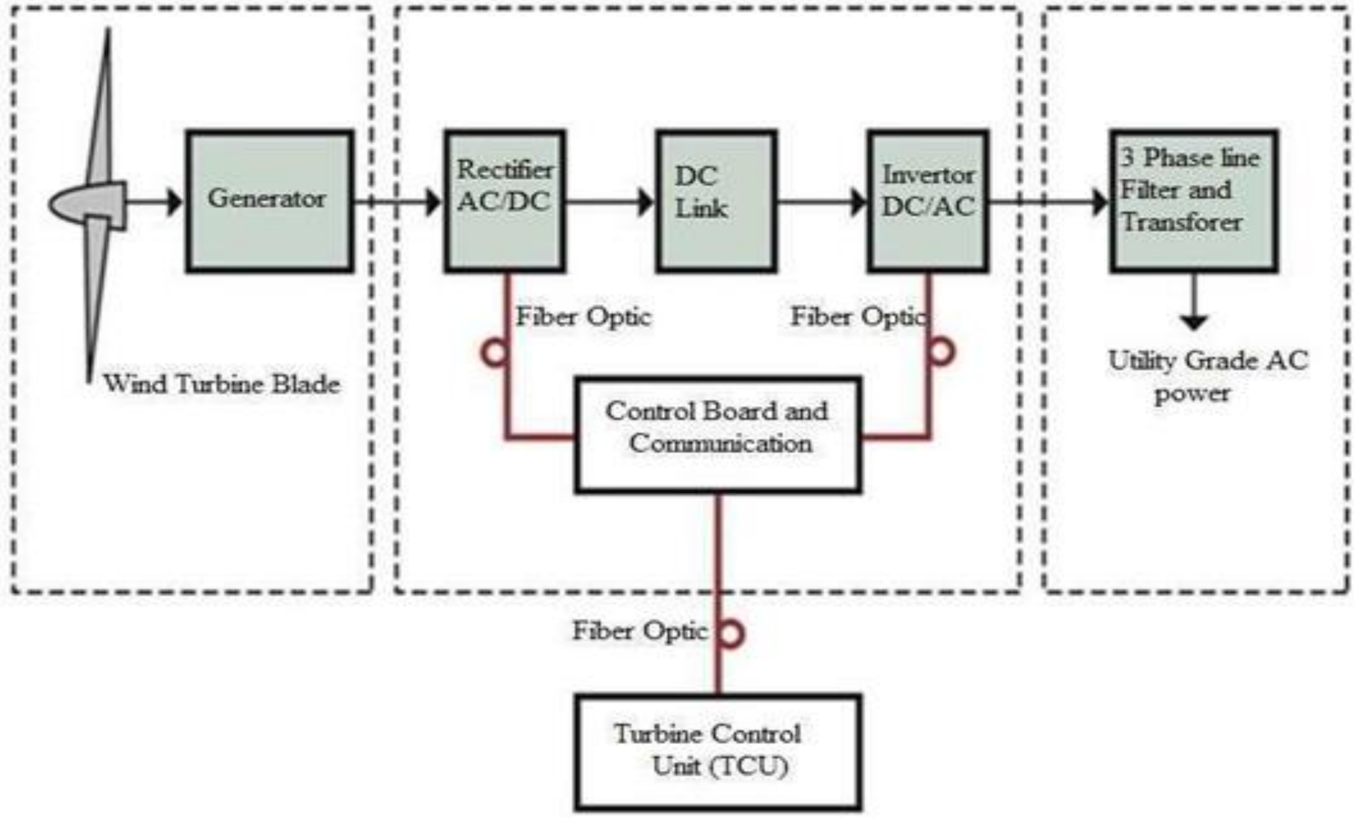

Figure. 2.2.7. Block Diagram of Vibration Analysis for Fault Detection[7]

The paper **"Vibration Analysis for Fault Detection of Wind Turbine Drivetrains—A Comprehensive Investigation"** presents an in-depth review of vibration-based condition monitoring techniques specifically aimed at detecting mechanical faults in wind turbine drivetrains. Mechanical faults such as gear wear, bearing damage, shaft misalignment, and imbalance are highlighted as major contributors to drivetrain failures. The study emphasizes the effectiveness of vibration analysis in identifying these issues early, helping prevent catastrophic damage and reduce maintenance costs. Various signal processing techniques like Fast Fourier Transform (FFT), Wavelet Transform.

Furthermore, the paper reviews experimental and real-world case studies that validate vibration analysis as a reliable diagnostic tool. It also explores the integration of machine learning algorithms and data-driven models to improve the accuracy and automation of fault diagnosis. The authors underline the importance of sensor placement, signal interpretation.

2.2.8 : Paper 8 [A methodological approach for detecting multiple faults in wind turbine blades based on vibration signals and machine learning] 2022

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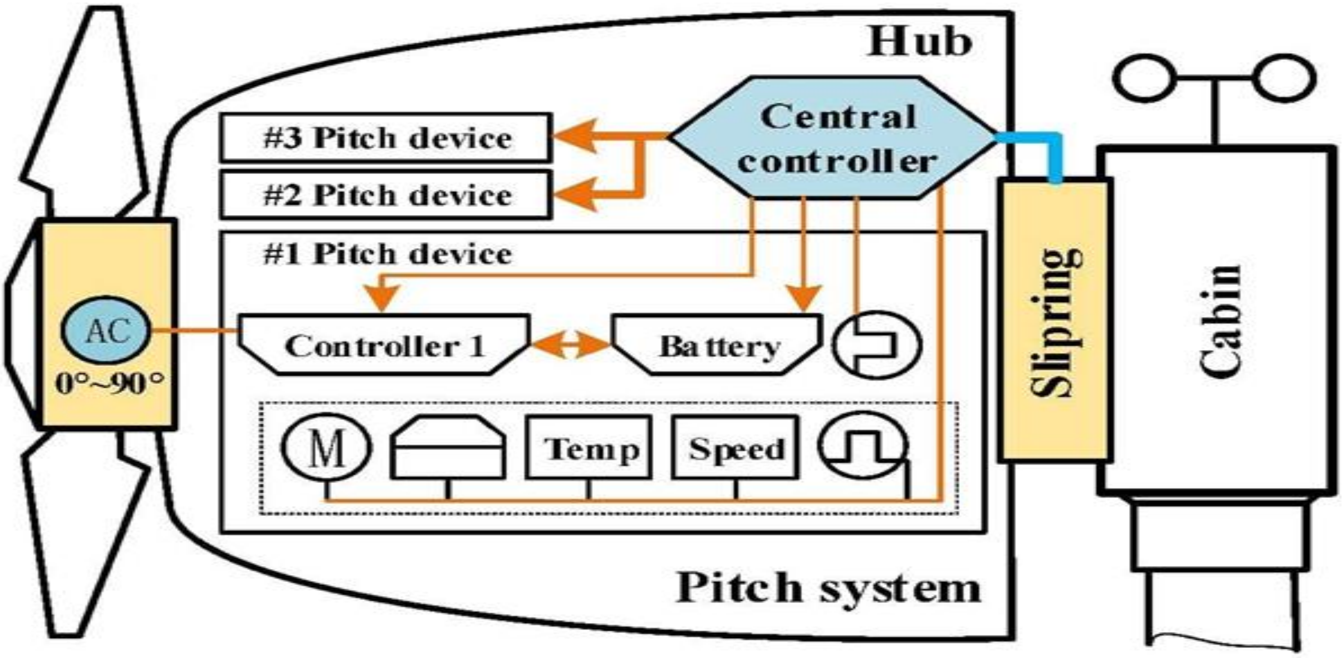

Figure. 2.2.8. Block Diagram of multiple faults Detection [8]

The paper "A Methodological Approach for Detecting Multiple Faults in Wind Turbine Blades Based on Vibration Signals and Machine Learning" presents a comprehensive method for identifying mechanical faults in wind turbine blades by analyzing vibration signals. The study emphasizes the use of advanced signal processing techniques to extract meaningful features from raw vibration data, which are typically generated due to various structural and mechanical anomalies such as cracks, delamination, or imbalance. These vibration patterns are then pre-processed and classified using machine learning algorithms, which help in accurately detecting the presence and type of fault in the turbine blades under different operational conditions.

Focusing on mechanical faults, the methodology includes steps like data acquisition through accelerometers, feature extraction using techniques such as time-domain and frequency-domain analysis, and fault classification using models like Support Vector Machines (SVM) or Artificial Neural Networks (ANN). The proposed approach demonstrates high accuracy in distinguishing between different types of blade faults, even when multiple faults coexist. This not only improves maintenance planning and turbine efficiency but also helps in preventing catastrophic failures by enabling early fault detection and diagnosis in wind turbine systems.

2.2.9 : Paper 9 [Deep Learning Method for Fault Detection of Wind Turbine Converter] 2024

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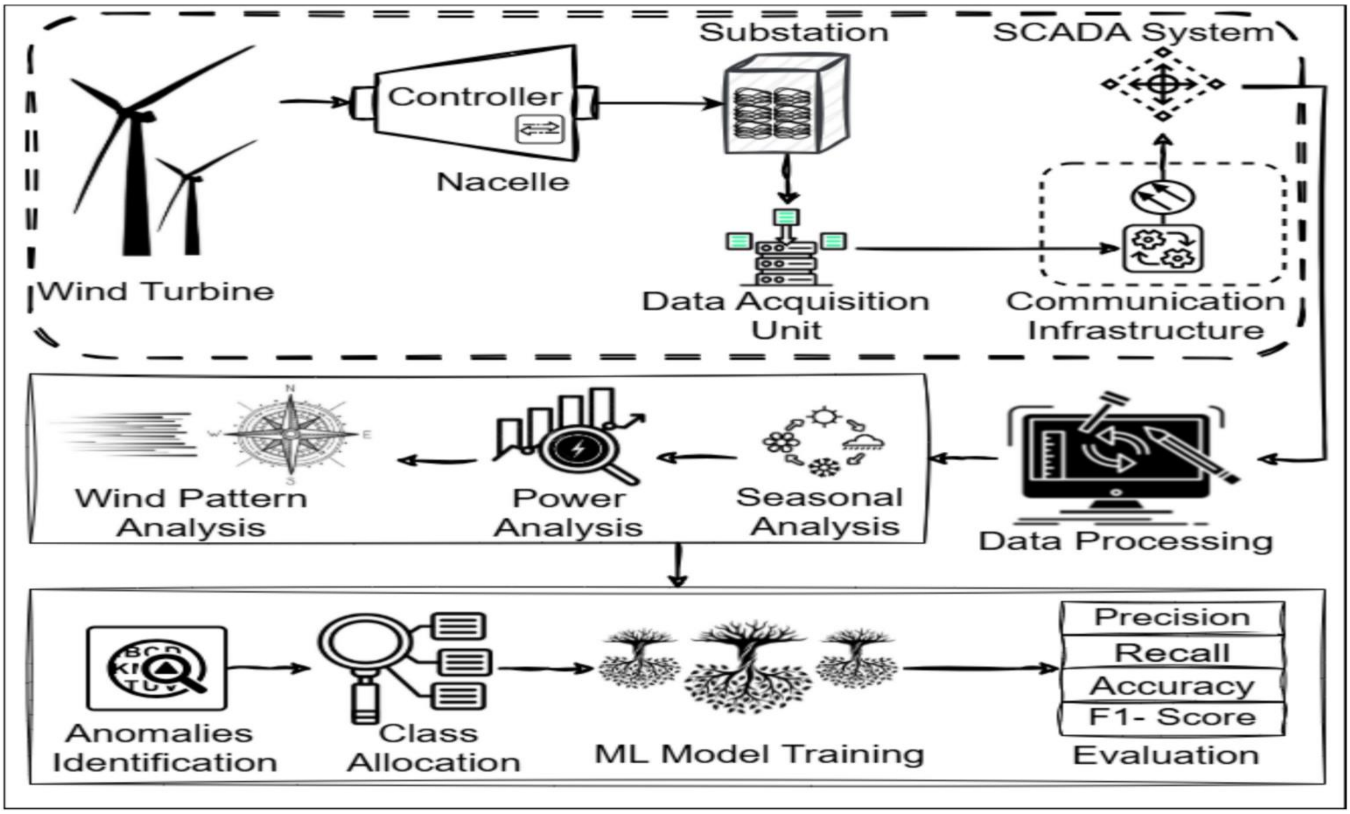

Figure. 2.2.9. Block Diagram Deep Learning Method faults Detection [9]

The paper **"Deep Learning Method for Fault Detection of Wind Turbine Converter"** introduces a deep learning-based approach to detect faults in wind turbine converters, with a particular emphasis on identifying mechanical-related anomalies. Although converters are primarily electrical components, their failure often stems from or leads to mechanical issues such as cooling fan malfunctions, vibration-induced structural stress, or component wear due to prolonged mechanical load. The study leverages deep learning models—specifically Convolutional Neural Networks (CNNs)—to analyze sensor data (including temperature, vibration, and current signals) and automatically learn features associated with fault conditions, without the need for manual feature extraction.

Focusing on mechanical faults, the research highlights how deep learning can detect early signs of mechanical degradation in converter components, such as abnormal vibrations from rotating parts or mechanical wear affecting heat dissipation. By training the model with labeled datasets under healthy and faulty operating conditions, the system achieves high accuracy in real-time fault detection. This deep learning approach enhances predictive maintenance strategies, reduces downtime, and ensures safer.

2.2.10 : Paper 10 [A Review of Recent Advances in Wind Turbine Condition Monitoring and Fault Diagnosis] 2022

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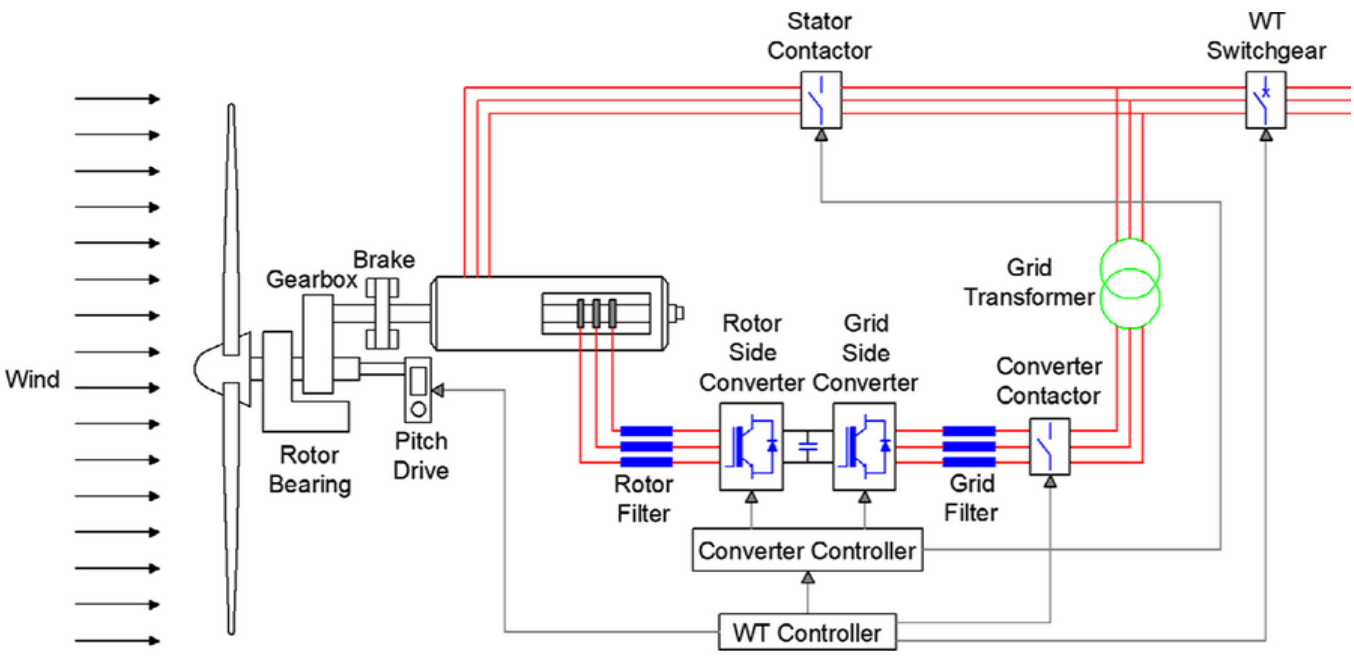

Figure. 2.2.10. Block Diagram Condition Monitoring and faults Detection[10]

The article **"A Review of Recent Advances in Wind Turbine Condition Monitoring and Fault Diagnosis"** provides a comprehensive overview of the latest techniques and technologies developed for monitoring the health and performance of wind turbines, with a strong emphasis on mechanical fault detection. Mechanical components such as bearings, gearboxes, shafts, and blades are prone to wear and failure due to the harsh and variable operating conditions in wind farms. The paper highlights that vibration analysis remains a dominant and reliable method for identifying mechanical faults, such as bearing defects, gear tooth damage, and unbalanced rotors. In addition, advanced signal processing methods like wavelet transform, empirical mode decomposition (EMD), and machine learning algorithms are increasingly being used to enhance the accuracy and early detection of such faults.

The review also underscores the integration of artificial intelligence (AI) and data-driven approaches in improving the reliability of condition monitoring systems. Machine learning techniques, particularly deep learning and neural networks, are being leveraged to analyze large volumes of sensor data for fault classification and prediction. Moreover, the paper discusses the growing use of wireless sensor networks and cloud-based monitoring platforms to facilitate real-time diagnostics and remote fault detection.

2.2.11 : Paper 11 [Fault Diagnosis of a Wind Turbine] 2023

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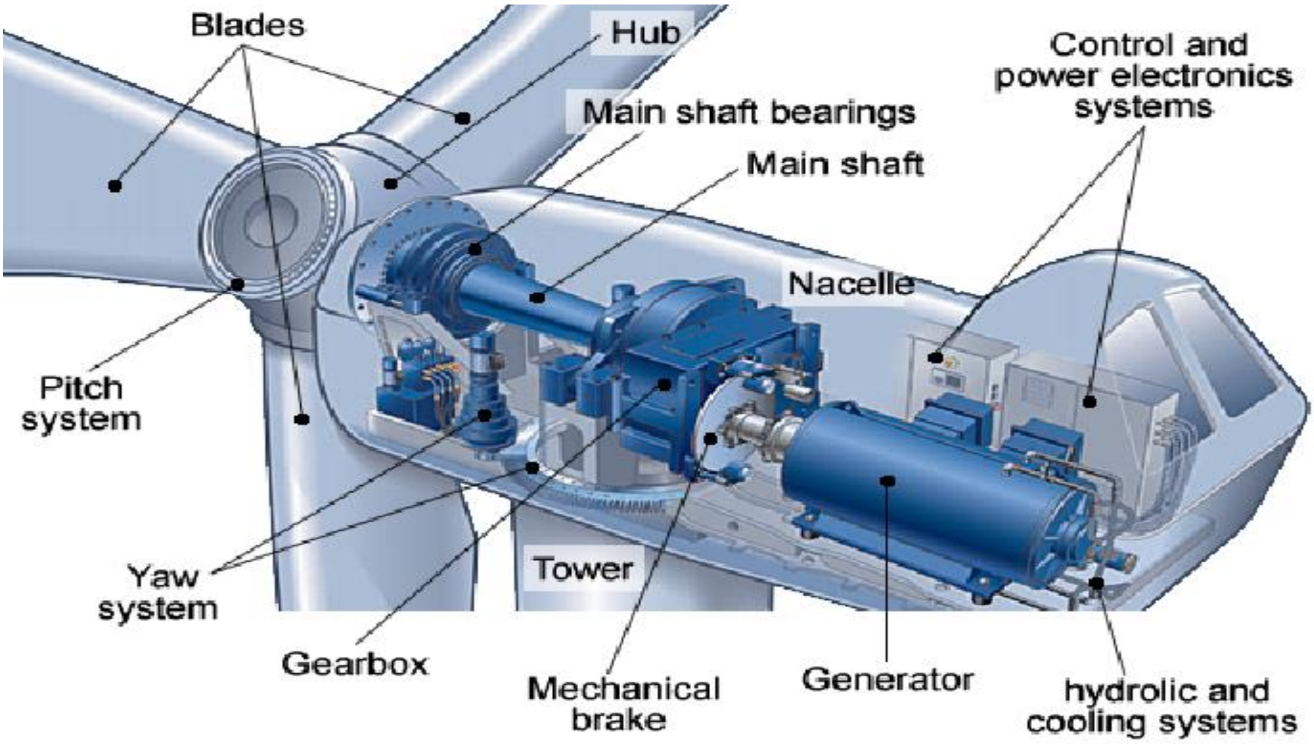

Figure. 2.2.11. Block Diagram faults Detection of a Wind Turbine [11]

Fault diagnosis of wind turbines is essential for ensuring operational reliability and minimizing downtime, especially as turbines are often located in remote and harsh environments. Mechanical faults are among the most common and critical issues encountered in wind turbines, typically affecting components such as the gearbox, bearings, blades, and generator. These faults can arise due to wear and tear, misalignment, imbalance, or lubrication failures. Techniques like vibration analysis, acoustic emission monitoring, oil analysis, and thermal imaging are widely used to detect and diagnose mechanical issues before they lead to catastrophic failures.

Advanced fault diagnosis methods increasingly incorporate machine learning, signal processing, and data-driven models to improve accuracy and early detection. Condition Monitoring Systems (CMS) collect real-time data from various sensors installed on the turbine to track changes in vibration patterns, temperature, and noise, which can indicate developing mechanical faults. Early diagnosis not only helps in planning maintenance activities efficiently but also extends the lifespan of turbine components and enhances the overall energy output by preventing unplanned outages.

2.2.12 : Paper 12 [A review on wind turbines gearbox fault diagnosis Methods.] 2025

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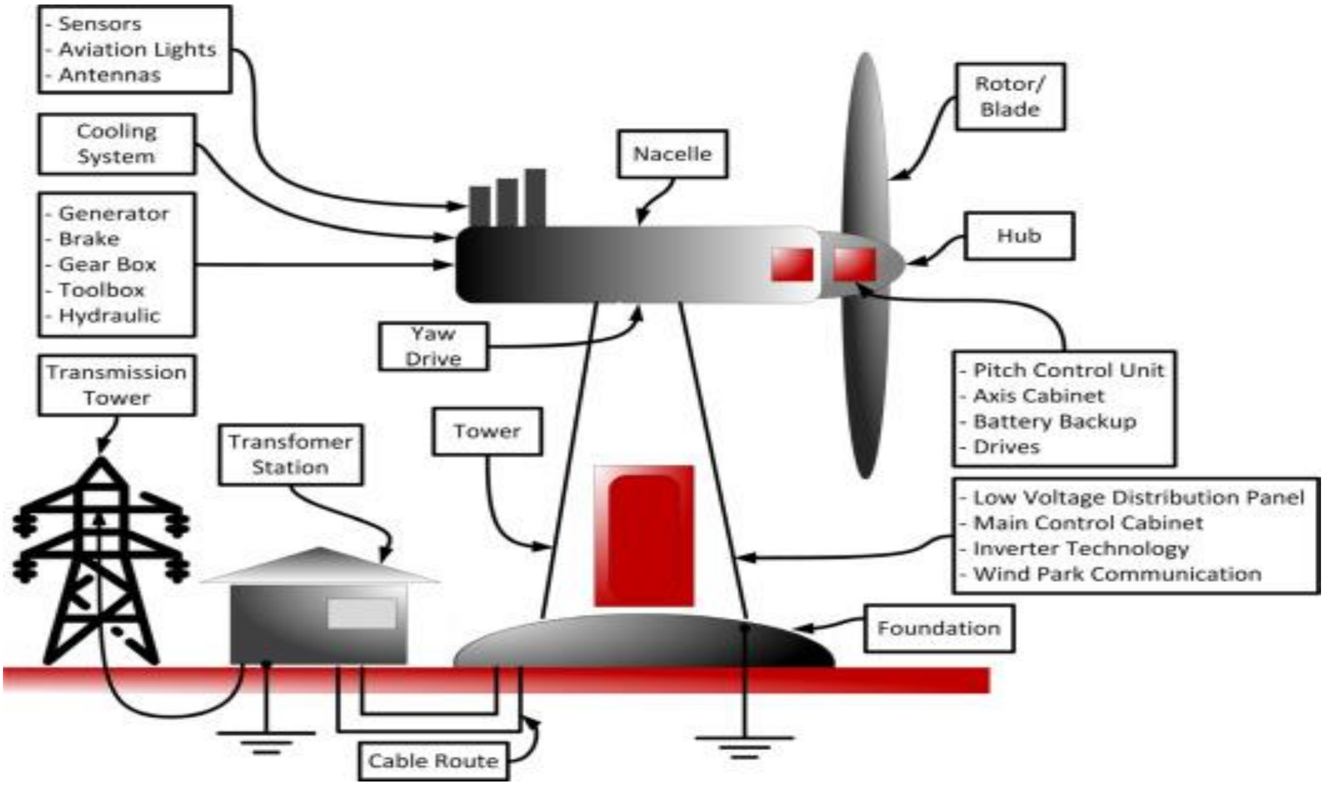

Figure. 2.2.12. Block Diagram on wind turbines gearbox fault Detection[12]

The paper **"A Review on Wind Turbines Gearbox Fault Diagnosis Methods"** provides a comprehensive overview of diagnostic techniques specifically targeting mechanical faults in wind turbine gearboxes, which are critical components responsible for speed and torque transmission. Due to harsh operational conditions, gearboxes are prone to faults such as gear wear, pitting, cracking, and bearing failures. The review emphasizes various condition monitoring techniques that rely heavily on vibration analysis, acoustic emission, and oil debris analysis. Among these, vibration-based methods are the most widely used due to their high sensitivity to mechanical anomalies and ability to detect early-stage faults.

Furthermore, the review explores the integration of intelligent fault diagnosis tools using machine learning and deep learning algorithms to improve fault classification accuracy. Techniques like Support Vector Machines (SVM), Artificial Neural Networks (ANN), and Convolutional Neural Networks (CNN) are increasingly being utilized to handle large-scale condition monitoring data and enhance automated diagnosis. Despite technological advancements, challenges remain in achieving robust real-time fault detection under varying load conditions and noise interference.

2.3 Summary Table

Sl. No	Title of the Journal Paper	Year Published	Methodology Used	Advantages	Drawbacks
1	Intelligent Monitoring and Control of Wind Turbine Prototype Using Internet of Things (IoT)	2022	IoT-based sensors and controllers to collect real-time wind turbine data, process it via cloud or edge computing.	Enables remote monitoring, predictive maintenanc e, efficiency optimization , and reduced costs.	Requires stable internet connectivity, poses cybersecurity risks, and may involve high initial setup costs.
2	IOT-Enabled Fault Diagnosis and Monitoring for Small Wind Turbine	2025	IoT-enabled sensors collect realtime data on wind turbine parameters (vibration, temperature)	Enables predictive maintenance, reduces downtime, and enhances efficiency.	High initial costs, cybersecurity risks, and dependency on stable internet connectivity
3	Fault Diagnosis and Monitoring of Small Wind Turbine	2024	sensor-based condition monitoring, signal processing and AI-based fault detection for early diagnosis.	Early fault detection, reduced maintenance costs, and increased turbine lifespan.	High initial setup cost, complexity in data interpretation, and potential sensor failures.

2.3 Summary Table

Sl. No	Title of the Journal Paper	Year Published	Methodology Used	Advantages	Drawbacks
4	Fault Diagnosis and Monitoring of Small Wind Turbine Using IOT	2023	IoT-based sensors monitor parameters and transmit data to a cloud-based system for real-time fault detection	Enables remote monitoring, predictive maintenance, and reduces downtime by identifying faults early.	Requires stable internet connectivity, initial setup costs, and potential cybersecurity risks.
5	Fault Detection and Isolation in Wind Turbines:Type3 Fuzzy Logic Systems and Adaptive Random Learning	2024	Uses threedimensional uncertainty modeling for fault detection, improving robustness and accuracy.	Handles high uncertainty, enhances fault classification	High computational complexity, requires expert knowledge.
6	An Early Fault Detection Framework for Wind Turbines using Vibration Signals	2024	vibration signal analysis with machine learning models to detect faults in wind turbines early.	Provides realtime monitoring, reduces maintenance costs, and prevents catastrophic failures.	Limited by sensor accuracy, high computational demands, and potential false positives.

2.3 Summary Table

Sl. No	Title of the Journal Paper	Year Published	Methodology Used	Advantages	Drawbacks
7	Vibration Analysis for Fault Detection of Wind Turbine Drivetrains—A Comprehensive Investigation	2023	Sensors measure vibrations in components like the gearbox and generator, and signals	Early, precise fault detection and continuous monitoring	High cost, complex analysis, and sensitivity to noise and sensor placement
8	A methodological approach for detecting multiple faults in wind turbine blades based on vibration signals	2022	Vibration signals from turbine blades are collected and processed to extract features.	High accuracy and capability to detect multiple faults simultaneously	Requires large datasets, high computational power, and complex model training.
9	Deep Learning Method for Fault Detection of Wind Turbine Converter	2024	Utilizes deep neural networks to analyze converterturbine system data for automatic fault pattern.	High accuracy and adaptive learning.	It requires large datasets and high computational resources.

2.3 Summary Table

Sl. No	Title of the Journal Paper	Year Published	Methodology Used	Advantages	Drawbacks
10	A Review of Recent Advances in Wind Turbine Condition Monitoring and Fault Diagnosis	2022	Utilizes signal processing, machine learning, and sensor data analysis for wind turbine fault diagnosis.	Enhances early fault detection and system reliabilit	It requires highquality data, complex algorithms, and incurs higher implementation costs.
11	Fault Diagnosis of a Wind Turbine.	2023	Wind turbine fault diagnosis uses sensor data processed signal analysis and AI/ML models to detect and classify faults.	Enables early, automated fault detection and maintenance planning.	high costs, complexity, and potential for false alarms.
12	A review on wind turbines gearbox fault diagnosis Methods.	2025	Utilizes vibration analysis, acoustic emission, oil and machine learning for early fault detection in gearboxes.	Enables predictive maintenance and reduces downtime	High sensor cost and complex data interpretation.

Chapter 3

3. Proposed Methodology

3.1 : Introduction

The proposed methodology aims to develop an efficient and real-time fault diagnosis system for small wind turbines (SWTs) using Internet of Things (IoT) technology, with a particular focus on mechanical faults. Mechanical issues such as bearing wear, shaft misalignment, blade imbalance, and gearbox failures can significantly reduce the efficiency and lifespan of wind turbines. Early detection and diagnosis of these faults are crucial to minimizing downtime and maintenance costs. This methodology leverages IoT-based sensors and data acquisition systems to continuously monitor the mechanical health of turbine components.

A network of IoT-enabled sensors—including vibration sensors, temperature sensors, acoustic sensors, and rotational speed sensors—is installed on critical mechanical parts of the wind turbine. These sensors collect real-time data and transmit it wirelessly to a cloud-based server or edge computing device. Data preprocessing techniques, such as noise filtering and normalization, are applied to ensure accurate analysis. Key performance indicators and abnormal patterns in vibration, temperature, and sound are analyzed to detect early signs of mechanical degradation.

The core of the diagnostic system lies in data analysis using machine learning algorithms or rule-based models trained to identify various mechanical fault signatures. Pattern recognition techniques and threshold-based fault classification enable the system to distinguish between normal operating conditions and potential mechanical failures. The system is designed to generate automated alerts or notifications when anomalies are detected, allowing for timely intervention and preventive maintenance.

To enhance system reliability and usability, a user-friendly dashboard is developed for remote monitoring via mobile or desktop interfaces. The integration of IoT and smart analytics not only facilitates real-time fault detection but also contributes to predictive maintenance strategies. This approach minimizes manual inspections and reduces operational risks, making it an ideal solution for remote or hard-to-access wind turbine installations. Overall, the proposed methodology offers a cost-effective and scalable solution for ensuring the mechanical reliability of small wind turbines.

3.2 : Proposed Methodology

3.2.1 : Block Diagram

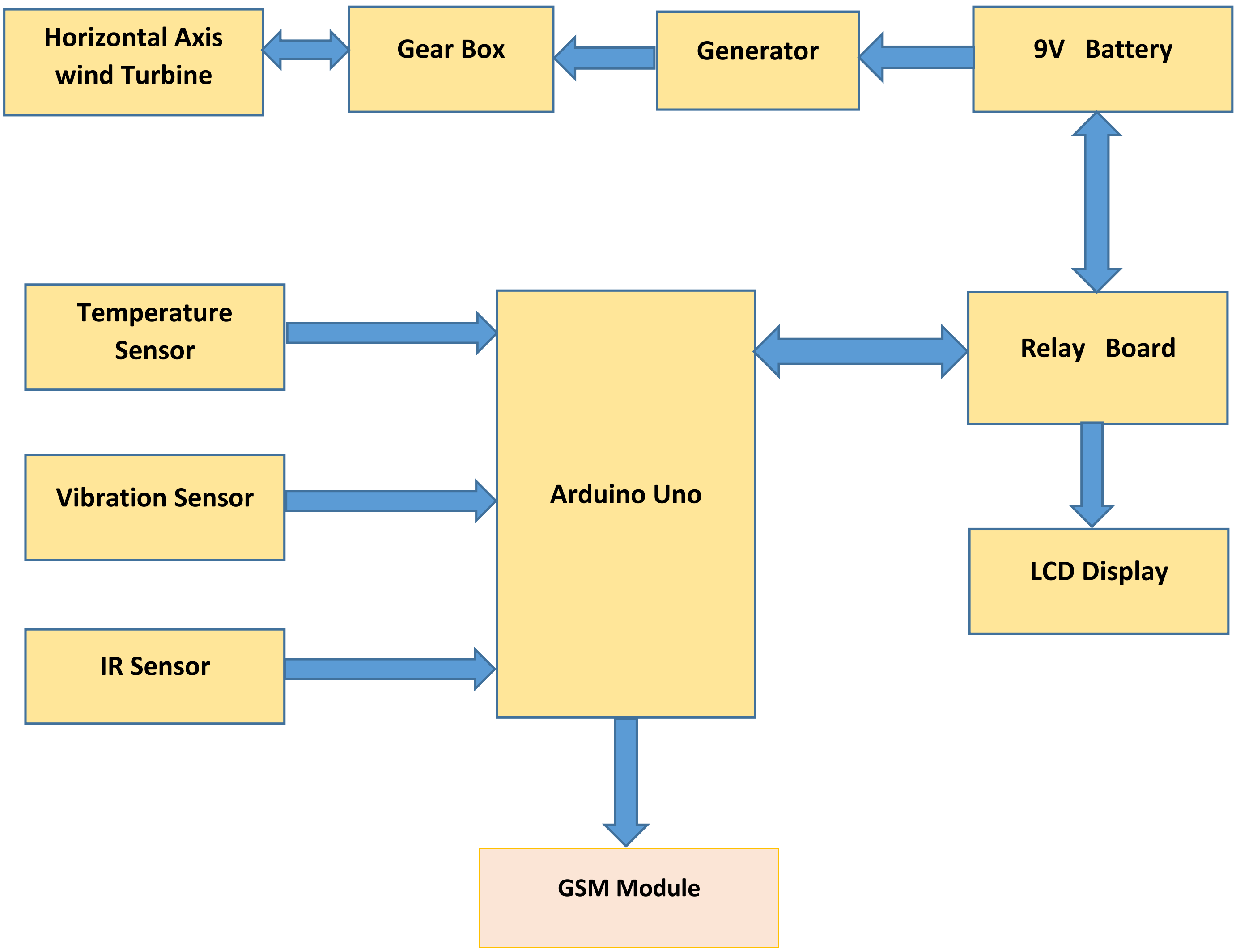

Figure. 3.2.1. Block Diagram of the Fault Detection and Monitoring of Small Wind Turbine .

3.2.2 : Flow Chart

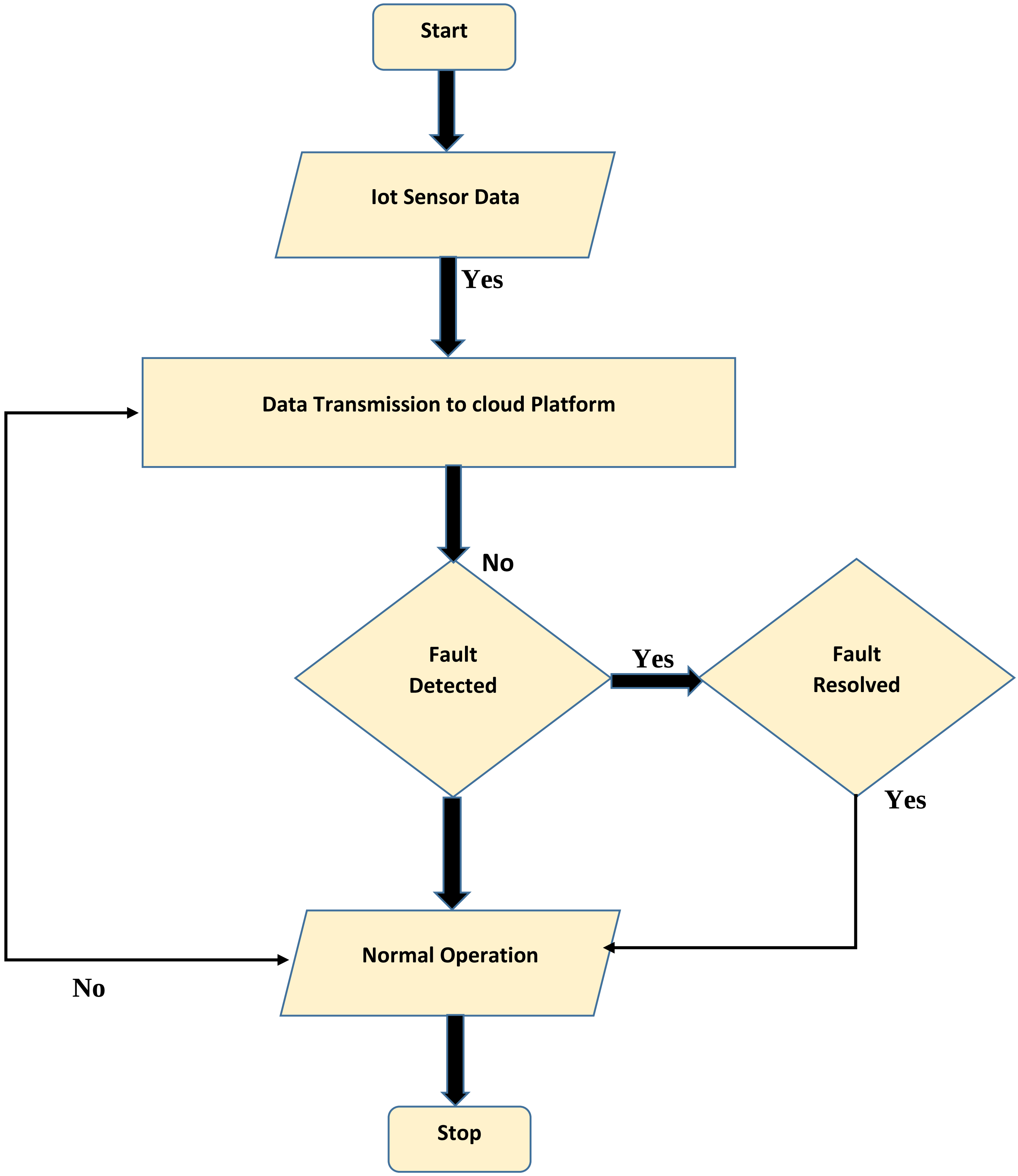

Figure 3.2.2 : Flow Chart of Proposed Block Diagram

3.3 : Investigation on Materials and Components Selected

3.3.1 Wind Turbines

Table 1. comparison of wind turbines

SI.No	**Features**	**Horizontal Axis wind Turbine.**	**Vertical Axis wind Turbine.**
1.	Starting wind Speed	Requires higher starting Wind speed.	Can start at lower wind speeds
2.	Efficiency	Higher Efficiency .	Lower Efficiency
3.	Installation Location	Requires open space	Suitable for urban or compact areas
4.	Maintenance	Harder (components are elevated)	Easier (components at ground level)
5.	Wind Direction Sensitivity	Needs to face wind (yaw mechanism required)	No mechanism needed.
6.	Power Output	Higher output, suitable for utility-scale	Lower output, suitable for small-scale use.

3.3.2: Controllers

Table 2. Comparison of controllers

SI.No	Features	MPPT Controller	Fuzzy logic Controller	PID Controller	DSP Based Controller
1.	Control Stategy	Maximum Power Point Tracking	Rule-based decision making	Proportional Integral	Digital Signal Processing
2.	Cost	Medium-High	Medium	Low- Medium	High
3.	Complexity	Moderate	High	Moderate	Complex
4.	Used for	Extracting maximum power from wind	Handling nonlinear, uncertain wind conditions	Torque & speed control	Real-time control and monitoring
5.	Efficiency	Very High	High	Moderate High	Very High

3.3.3: Temperature sensors

Table 3. Comparison of Temperature Sensors

SI.No	Features	Thermocouple (Type K)	RID (Pt100)	Thermistor (NTR/PTC)	Infrared (IR) Sensor
1.	Sensing Element	Metal junction	Platinum resistor	Ceramic/polymer resistor	Non-contact optical
2.	Accuracy	Moderate (±1–2°C)	High (±0.10.5°C	High (±0.2–1°C)	Moderate (±1–2°C)
3.	Response Time	Fast	Moderate	Fast	Very Fast
4.	Temperature Range	-200 to +1250	-200 to +850	-50 to +150	-70 to +1000
5.	Cost	Low-Medium	Medium	Low	Medium-High

3.3.4 : Vibration sensors

Table 4. Comparison of Vibration Sensors

SI.No	Features	Piezoelectric Sensor	MEMS Accelerometer	Capacitive Sensor	IEPE Accelerometer
1.	Sensitivity	High	Moderate to High	Moderate	Very High
2.	Frequency	Wide (1 Hz to 10 kHz+)	Narrow to Moderate (up to 2 kHz)	Limited (few Hz to 1 kHz)	Very Wide (up to 20 kHz)
3.	Power Consumption	Low	Very Low	Low to Moderate	Requires constant current supply
4.	Mounting Type	Surface or bolt-on	PCB, adhesive, embedded	Integrated or custom	Stud or magnet mount
5.	Typical Use in Wind Turbine	Detects blade imbalance, bearing faults	Low-cost monitoring of tower vibrations and general motion	Measures lowfrequency structure vibrations	High-precision measurement of gear/bearing vibration .

3.3.5: Voltage sensors

Table 5. Comparison of Voltage Sensors

SI.No	Features	Hall Effect Voltage Sensor	Voltage Divider Sensors	Capactive Voltage sensor	Resistive Voltage Sensor
1.	Voltage Range	±25V to ±1000V	0V to 1000V+ (scalable)	0V to 500V AC	0V to 250V (typical)
2.	Accuracy	Moderate to High	Moderate	Moderate	Low to Moderate
3.	Isolation	Yes (Galvanic)	No	Yes	No
4.	Response Time	Fast (µs to ms)	Fast (µs)	Moderate	Fast
5.	Typical Use in Wind Tubine	DC/AC output voltage monitoring, isolated from high voltage	Basic monitoring of generator or battery voltage	Non-contact voltage detection on transmission lines	Low-cost applications where isolation isn't a priority

3.3.6: Main Components

Table 6: Selected components

SI.NO	Components	Purpose/Function	Approximate Cost
1.	Small Wind Turbine	Main system to be menitored	₹ 3,000 - ₹ 8,000
2.	Vibration Sensor	Detect mechanical faults	₹150 - ₹400
3.	Temperature Sensor	Monitor overheating	₹50 - ₹200
4.	Current Sensor	Measure output current	₹250 - ₹400
5.	Voltage Sensor	Monitor voltage levels	₹100 - ₹200
6.	Arduino Uno	Interface and control unit	₹800 - ₹1,500
7.	GSM Module	SMS alerts in case of faults	₹500 - ₹800
8.	Battery	Powering System	₹2,000 - ₹4,000

3.4 : Conclusion

The diagnosis of mechanical faults in small wind turbines using IoT technology provides a modern and efficient approach to maintaining system health and ensuring operational continuity. Mechanical faults such as bearing wear, shaft misalignment, and gearbox failures often go unnoticed in traditional monitoring systems until significant damage occurs. The integration of IoT allows for real-time data acquisition and remote monitoring, making it possible to detect anomalies before they lead to system breakdowns. IoT-enabled sensors collect critical mechanical parameters like vibration, temperature, and rotational speed, which are analyzed using edge computing or cloud-based platforms. This proactive fault detection strategy minimizes downtime and maintenance costs while enhancing the safety and reliability of the wind turbine system. The real-time insights help operators make informed decisions regarding maintenance scheduling and component replacement.

By focusing solely on mechanical faults, the system becomes more specialized and sensitive to physical anomalies within the turbine structure. This targeted approach avoids data overload and ensures that the most relevant mechanical issues are addressed with higher accuracy. The continuous monitoring of mechanical components reduces the risk of sudden failure and extends the turbine's operational lifespan. In summary, IoT-based fault diagnosis tailored for mechanical faults in small wind turbines represents a significant advancement in condition-based maintenance. It combines smart sensing technology with intelligent analytics to offer a scalable and cost-effective solution. As the demand for renewable energy grows, such innovative monitoring systems will be crucial in ensuring the sustainability and efficiency of decentralized wind energy generation.

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