Offshore wind turbines (OWTs) represent a critical component in the transition towards sustainable energy sources,

offering substantial benefits due to their high energy yield and reduced visual and noise impacts compared to onshore wind farms.

OWTs operate in harsh marine environments, subjecting them to various stressors such as strong winds, waves, and corrosive saltwater. These conditions can lead to structural fatigue, component degradation, and unexpected failures, posing significant safety risks and increasing maintenance costs.

Traditional inspection and maintenance methods for OWTs are labour-intensive, costly, and often require downtime, which affects the turbines' operational efficiency. There is a critical need for an effective Structural Health Monitoring (SHM) system that can continuously monitor the structural integrity of OWTs, detect early signs of damage, and provide timely diagnostics to prevent catastrophic failures.

Structural Health Monitoring (SHM) has emerged as a pivotal approach to ensure the safety, reliability, and cost-effectiveness of OWTs.

SHM involves the integration of sensing technologies, data analysis, and predictive maintenance strategies to detect and diagnose structural

issues before they escalate into serious problems.

### Problem Statement

#### Structural Health Monitoring of Offshore Wind Turbines using Functional Accelerometer Data

The global demand for renewable energy has led to the rapid expansion of offshore wind farms, which are pivotal in harnessing wind energy to generate electricity. Offshore Wind Turbines (OWTs) operate in harsh marine environments, subjecting them to various stressors such as strong winds, waves, and corrosive saltwater. These conditions can lead to structural fatigue, component degradation, and unexpected failures, posing significant safety risks and increasing maintenance costs.

Traditional inspection and maintenance methods for OWTs are labor-intensive, costly, and often require downtime, which affects the turbines' operational efficiency. There is a critical need for an effective Structural Health Monitoring (SHM) system that can continuously monitor the structural integrity of OWTs, detect early signs of damage, and provide timely diagnostics to prevent catastrophic failures.

The use of accelerometer data for SHM presents a promising solution due to its ability to capture dynamic responses of structures under operational loads. However, challenges remain in processing and analyzing the vast amounts of accelerometer data to extract meaningful information about the structural health of OWTs. The development of advanced data processing techniques and machine learning algorithms is essential to transform raw accelerometer data into actionable insights.

This project aims to address these challenges by developing and validating a comprehensive SHM system for OWTs using functional accelerometer data. The primary objectives include designing an efficient data acquisition system, implementing robust data processing methods, and applying machine learning models to detect and diagnose structural issues. The successful implementation of this SHM system will enhance the safety, reliability, and longevity of offshore wind turbines, thereby contributing to the sustainable growth of the renewable energy sector.

By tackling these issues, the project seeks to provide a cost-effective and reliable solution for the continuous monitoring and maintenance of OWTs, ultimately leading to improved operational performance and reduced maintenance costs.

### Introduction

#### Background

Offshore wind turbines (OWTs) represent a critical component in the transition towards sustainable energy sources, offering substantial benefits due to their high energy yield and reduced visual and noise impacts compared to onshore wind farms. However, the harsh marine environment in which these structures operate imposes significant challenges to their maintenance and longevity. Structural Health Monitoring (SHM) has emerged as a pivotal approach to ensure the safety, reliability, and cost-effectiveness of OWTs. SHM involves the integration of sensing technologies, data analysis, and predictive maintenance strategies to detect and diagnose structural issues before they escalate into serious problems.

Among the various sensing technologies available, accelerometers have gained prominence due to their sensitivity to vibrations and structural responses. Functional accelerometer data, which includes time-series measurements of acceleration at various points on the structure, provides valuable insights into the dynamic behavior of OWTs. This data can be used to detect anomalies, assess structural integrity, and predict potential failures.

The importance of SHM in OWTs cannot be overstated. These structures are subjected to a multitude of dynamic loads, including wind, waves, and operational forces, which can lead to fatigue, corrosion, and other degradation mechanisms. Early detection of structural issues can significantly reduce maintenance costs and downtime, enhance the safety of operations, and extend the service life of the turbines. Consequently, the development and implementation of effective SHM systems are critical for the economic and operational viability of offshore wind farms.

#### Structural Health Monitoring (SHM) of Offshore Wind Turbines

The SHM of offshore wind turbines involves a comprehensive approach to monitoring, diagnosing, and managing the health of these structures. It encompasses several stages, including data acquisition, processing, and interpretation. Accelerometers are often deployed at strategic locations on the turbine, such as the tower, nacelle, and blades, to capture vibrational data. This data is then analyzed to identify patterns and anomalies that may indicate structural damage or degradation.

1. \*\*Data Acquisition\*\*: High-resolution accelerometer data is collected continuously or at regular intervals to monitor the dynamic responses of the turbine. This data reflects the vibrational characteristics of the structure under various loading conditions.

2. \*\*Data Processing\*\*: The raw accelerometer data is processed to remove noise and extract meaningful features. Techniques such as filtering, spectral analysis, and time-frequency analysis are employed to enhance the quality of the data and reveal hidden patterns.

3. \*\*Damage Detection and Diagnosis\*\*: Advanced algorithms and machine learning techniques are applied to the processed data to detect anomalies and diagnose potential structural issues. These methods can identify deviations from normal operational behavior, such as changes in natural frequencies, damping ratios, and mode shapes.

4. \*\*Predictive Maintenance\*\*: By analyzing the trends in the accelerometer data over time, predictive maintenance strategies can be developed. These strategies aim to anticipate potential failures and schedule maintenance activities proactively, thereby minimizing downtime and repair costs.

#### Functional Accelerometer Data in SHM

Functional accelerometer data plays a crucial role in the SHM of OWTs due to its ability to capture the dynamic responses of the structure with high precision. This data provides detailed information about the vibrational behavior of the turbine, which is influenced by both external forces and the inherent properties of the structure. By continuously monitoring these responses, it is possible to detect early signs of structural deterioration, such as cracks, loosening of joints, and other forms of damage.

The use of functional accelerometer data in SHM involves several key challenges, including the need for robust data processing techniques to handle the large volumes of data generated, the development of accurate models to interpret the data, and the integration of these models into a comprehensive SHM framework. Despite these challenges, the potential benefits of using accelerometer data for SHM are substantial, including improved safety, reduced maintenance costs, and extended service life of OWTs.

### Objectives

The primary objective of this MSc project is to develop and validate an effective SHM system for offshore wind turbines using functional accelerometer data. The specific objectives include:

1. Designing a robust data acquisition system for collecting high-quality accelerometer data from OWTs.

2. Developing advanced data processing techniques to extract meaningful features from the accelerometer data.

3. Implementing machine learning algorithms for damage detection and diagnosis based on the processed data.

4. Evaluating the performance of the proposed SHM system through simulations and experimental validations.

### Structure of the Thesis

This thesis is structured as follows:

1. \*\*Chapter 2\*\*: Literature Review - An overview of existing SHM techniques and their application to offshore wind turbines.

2. \*\*Chapter 3\*\*: Methodology - A detailed description of the data acquisition, processing, and analysis methods used in this study.

3. \*\*Chapter 4\*\*: Data Analysis and Results - Presentation and discussion of the findings from the analysis of accelerometer data.

4. \*\*Chapter 5\*\*: Case Study - Application of the proposed SHM system to a specific offshore wind turbine and evaluation of its performance.

5. \*\*Chapter 6\*\*: Conclusion and Future Work - Summary of the key findings, conclusions, and recommendations for future research.

By addressing these objectives and following this structure, this project aims to contribute to the advancement of SHM techniques for offshore wind turbines, ultimately enhancing their reliability and operational efficiency.