INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
PhD-17 SHORT ABSTRACT OF THESIS

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Thesis Title: **Predictive Maintenance in Renewable Energy Systems using Advanced Artificial Intelligence Techniques**

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SHORT ABSTRACT

Due to major industrial expansions, population growth, and a steep rise in per capita energy consumption, the world's energy demand has been steadily rising. A large amount of energy needs are met by electricity. The production of electricity using fossil fuels has nearly achieved saturation due to environmental factors and the finite supply of fossil fuels. Therefore, renewable energy sources must fill the gap between demand and supply.

Numerous Photovoltaic (PV) modules connected via cables, junction boxes, converters, battery banks, inverters, and other devices may make up a typical solar PV system. PV modules arranged as arrays, connected to inverters through DC subsystems, with the inverters connected to AC subsystems attached to a grid, make up a grid-connected PV system. Because they are subjected to adverse and unpredictable environmental conditions, including severe weather, rain, heat, storms, dust, snow, etc., PV arrays that are installed outdoors are vulnerable to a variety of defects. Furthermore, compared to other subsystems, inverter errors are more common in PV systems; as a result, they have a major influence on how much energy a PV system can generate. Early detection of inverter faults enables a reduction in system downtime. Even though PV systems are becoming more and more common across all renewable energy sources, faults are serious concerns for their efficiency, safety, and reliability.

Predictive maintenance makes use of predictive tools to decide when to take maintenance actions by monitoring a machine or process continuously, thereby allowing maintenance action only when it is necessary. Predictive maintenance is becoming increasingly prevalent in renewable energy systems due to advancements in sensors, computational power, and the availability of smart and ubiquitous devices. Predictive maintenance is essential for renewable energy systems because a malfunctioning component or faulty equipment can cause power fluctuations, decreased performance, costly downtime, system failure, or even catastrophic failures. PV monitoring systems continuously produce enormous amounts of data. Data-driven prognostics and diagnostics can be accomplished by using Machine learning (ML) and Artificial Intelligence (AI) techniques.

This dissertation focuses on the development of advanced AI-based models for early fault detection and diagnosis in renewable energy systems, with a particular emphasis on solar PV systems. The four major contributions are as follows. First, fault detection using regression models is explored where advanced regression techniques, including ensemble methods, deep learning (DL), and contextual DL approaches are utilized to predict AC power and detect anomalies by comparing predicted and actual power values. As part of the second contribution, a novel Context-Sensitive LSTM (CS-LSTM) model is proposed which integrates contextual features like weather conditions and time of day to enhance prediction accuracy for regression-based fault detection. Building classification-based methods to identify and categorize faults into normal and anomalous groups is the third contribution. To address issues with data imbalance, traditional and deep learning classifiers are investigated with a focus on feature selection and data augmentation techniques. To detect and classify PV faults with special emphasis on inverter faults, including earth faults, straight joint faults, IGBT (Insulated Gate Bipolar Transistor) faults, and overtemperature faults, a predictive maintenance framework that integrates regression and classification techniques has been finally developed. This framework uses CS-LSTM and incorporates contextual data to demonstrate the model's diagnostic and predictive abilities.

This research investigates various AI techniques, including traditional ML models, Recurrent Neural Network (RNN) based sequential models, context-integrated ML models, and contextual DL models to predict and classify faults in solar PV systems. The conventional ML models are not effective for early prediction of faults in solar PV systems. However, significant improvements are observed in early fault prediction with our proposed methodologies with RNN-based sequential models, and contextual DL models when contextual features are incorporated with these models. This research demonstrates the effectiveness of integrating contextual information into machine learning models, highlighting its potential for early fault detection and diagnosis in solar PV systems. It is anticipated that the contributions made in this thesis can be applied for early fault prediction of PV systems well in advance. It contributes to the growing field of predictive maintenance, providing practical tools to increase the reliability and efficiency in the operation of renewable energy systems.