



Chapter 8

Condition Monitoring and Fault Detection With AI and Digital Twin Technologies

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ABSTRACT

As the world moves toward renewable energy, wind power stands out as a key sustainable source. However, wind turbines face challenges in reliability due to harsh conditions, mechanical wear, and electrical stress. Traditional maintenance falls short for large wind farms. This chapter explores how Artificial Intelligence (AI) and Digital Twin technologies enable real-time monitoring of blades, gearboxes, bearings, generators, and converters. AI models like Neural Networks, Support Vector Machines, Convolutional Neural Network (CNN), and Long Short-Term Memory (LSTM) help detect faults and predict failures early. Digital twins enhance diagnostics by simulating turbine behavior using real-time data. The chapter also covers hybrid modeling, anomaly detection, and federated learning. Case studies include offshore

DOI: 10.4018/979-8-3373-4159-0.ch008

wind AI, blade crack detection, and converter diagnostics. Challenges include data quality, cybersecurity, and scalability. Future trends point to edge AI, cloud-based diagnostics, and blockchain for secure monitoring and predictive maintenance.

INTRODUCTION

The importance of wind energy has shifted in importance in response to the adoption of clean energy generation by different countries across the globe. This has resulted in the construction of wind turbines that are slap on growing in size globally. These wind turbines are also getting complex and are becoming harder to service because they are increasingly being built offshore. These matters are primarily operational in nature and are proving to be the primary challenge. The problems are also emerging in the context of serviceable dependency and effectiveness. The combination of scheduled fault prevention approach and the reactive maintenance strategy, leads to unplanned downtime and even safety risks. More so, there are unplanned and unaccounted safety risks. The operational use of AI and the rest of the advanced Fourth Industrial revolution technologies such as Digital twins have proven useful in wind energy apparatus optimization. Condition monitoring that drives AI and Digital Twins based strategies plays a critical role by assessing the condition of blades, generators and gearboxes. Blades, gearboxes and generators are known to be some of the most problematic reactive. The turbines are also reactive, meaning the condition of the turbine must also be evaluated. Otherwise, there are significant passive monitoring adversarial repercussions. Anomalies as well as the downward trends of the various units are corrected through the application of IoT and advanced AI models before they occur. The digital twin also augments the process by developing dynamically changing virtual models of turbines under predictive simulations and performance improvement optimization. The lifetime operational risk and cost of a machine are decreased considerably when there is a shift from reactive to predictive maintenance, which is made possible through the application of AI and digital twins technology. This chapter lays the groundwork to grasp the focus of these new technologies innovations towards integrating the monitoring and diagnostics of wind turbine and energy system sustainability (Bassey, 2022b).

Importance of Condition Monitoring in Wind Energy

Keeping track of all these conditions is integrated in new wind technology through monitoring, which helps in these new systems functioning safely, reliably and in a cost-effective manner. The blades, gearboxes, bearings, and generators of a wind turbine are put through extreme fluctuations and rough environmental conditions,

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