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Enhancing Wind Turbine Fault Prediction through Integrated SCADA Data Analysis and Machine Learning Techniques

Authors : Sergey Bronskiy, Jack C. P. Cheng, Chris K. C. Cheung, Tianxiang Jiang

Abstract : Ensuring the resilience and protection of power systems is paramount in the integration of renewable energy sources such as wind turbines. This study introduces a sophisticated condition monitoring framework utilizing Supervisory Control and Data Acquisition (SCADA) systems alongside advanced machine learning techniques to enhance situational awareness and proactive maintenance. Focusing on critical events in wind turbine operations this research leverages a comprehensive dataset from the Penmanshiel wind farm, containing over 3.6 million SCADA records and detailed event logs spanning five years. Addressing challenges like high data dimensionality, complex non-linear relationships, and significant class imbalances, the methodology employs rigorous data preprocessing, including anomaly detection, data cleaning, and data integration. Feature selection is optimized through Mutual Information and Lasso Regression, while Gradient Boosting algorithms, notably XGBoost and LightGBM, enhanced by Genetic Algorithms, provide robust predictive capabilities. The SMOTETomek technique ensures balanced datasets, resulting in models that achieve over 96% accuracy and F1-scores. Statistical validation via the Wilcoxon Signed-Rank Test confirms the significance of these improvements. This research contributes to power system resilience by enabling real-time situational awareness and protection-focused condition monitoring, facilitating proactive maintenance strategies that minimize downtime, and enhancing the reliability and stability of power infrastructures.

Keywords : gradient boosting, machine learning, predictive maintenance, scada data, wind turbines
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