Requirements

Windmill Farm Cooperative AI for Predictive Maintenance

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Subject

Windmill farm where minimum 6 windmills will cooperated in training updating an AI model which is used to predict maintenance need

Purpose

This document defines the main requirements for a system where several wind turbines collaborate to predict maintenance needs using artificial intelligence. The goal is to improve reliability and reduce downtime by enabling turbines to learn collectively from their operational data.

Scope

The system includes local sensors and gateways on each windmill, a central data and training environment, and basic monitoring tools. The architecture should be modular and scalable, based on two main environments:

- a **local layer** on each turbine for short-term data collection, quick analyses, and first-level anomaly detection;
- a **central layer** (cloud or data center) for long-term data storage, AI model training, and coordination between turbines.

Functional requirements

FR-1: **Collect data:** Gather sensor data (temperature, vibration, power output, etc.) from each turbine in real time.

FR-2: **Validate and store:** Ensure collected data is complete and properly time-stamped before storing it.

FR-3: **Access data:** Allow authorized users and systems to retrieve raw or summarized data for analysis.

FR-4: **Monitor system health:** Provide a simple way to check that the system and its services are working correctly.

FR-5: **Collaborative AI training:** Enable multiple turbines to contribute to a shared AI model that predicts maintenance needs, either through centralized or distributed updates.

FR-6: **Model management:** Keep track of AI model versions, their performance, and allow safe updates or rollbacks.

FR-7: **Prediction service:** Provide real-time predictions about potential maintenance issues and their urgency.

FR-8: **Alerts and notifications:** Inform operators when the risk of failure or anomaly exceeds a set threshold.

FR-9: **Edge logic:** Each turbine's local system should:

- temporarily store recent data in case of network interruptions;
- run simple AI checks to detect unusual patterns early;
- reduce the amount of data sent to the central system by summarizing or filtering it.

FR-10: **Central coordination:** The main cloud or data center gathers updates from turbines, stores long-term data, and provides datasets for AI training and trend analysis.

Non-functional requirements

NFR-1: **Availability:** The system should remain operational most of the time, with only minimal downtime.

NFR-2: **Responsiveness:** Maintenance predictions should be provided quickly enough to allow preventive action.

NFR-3: **Scalability:** The solution must handle a growing number of turbines and data without major redesign.

NFR-4: **Reliability:** Data transfers and updates should remain consistent even in case of connection issues.

NFR-5: **Security:** Data exchanges and storage must be protected from unauthorized access.

NFR-6: **Data lifecycle:** Organize data into short-term (local), medium-term (central active), and long-term (archived) categories, with automatic cleanup or compression over time.

Data requirements

DR-1: **Data format:** Define a clear structure for sensor data including identifiers, timestamps, and measurements.

DR-2: **Time consistency:** Ensure all turbines use synchronized time references for accurate comparisons.

DR-3: **Sampling rate:** Specify how frequently each type of sensor collects data.

DR-4: **Maintenance labels:** Record the time and nature of maintenance actions to improve AI training.

DR-5: **Data transfer policy:** Decide when and how local systems send data to the central cloud (e.g., periodic uploads, alerts, or summaries).

Security & privacy

SEC-1: Protect all communications and stored data through encryption.

SEC-2: Require authentication before data can be sent or accessed.

SEC-3: Limit access rights depending on user roles.

SEC-4: Store only the information necessary for maintenance prediction.

SEC-5: Secure local storage on turbines and ensure safe synchronization with central systems.

Testing & operations

OPS-1: Test the system with at least six turbines to validate real conditions.

OPS-2: Monitor system activity, data flows, and model accuracy.

OPS-3: Back up important data and trained models regularly.

OPS-4: Check synchronization between local turbine systems and the central environment to prevent inconsistencies.

Minimum Viable Product checklist

- At least six turbines sending data to the system.
- Local data buffering and basic anomaly detection on each turbine.
- Central environment for long-term storage and AI training.
- Deployed model providing real-time maintenance predictions.
- Simple dashboard displaying current turbine status and alerts.
- Basic system health check and secure access implemented.

Notes

The combination of local and central data processing reduces network load and improves system resilience. Decisions to be made include:

- how much data to keep locally and for how long;
- where to run the local AI analysis (directly on the turbine or nearby);
- how to manage the long-term data storage and model updates efficiently.