Requirement Analysis: Weather-Based Prediction of Wind Turbine Energy Output (Next-Generation Approach)

1. Problem Definition

Wind energy production depends on weather conditions such as wind speed, air density, turbulence, temperature, and pressure.

Goal: Develop an intelligent system to forecast wind turbine energy output accurately using real-time and historical data.

2. Stakeholders

- Wind farm operators
- Energy grid managers
- Renewable energy analysts
- Maintenance teams
- Energy traders & policymakers

3. Functional Requirements

Data Acquisition:

- Weather: wind speed, direction, temperature, pressure, humidity, turbulence, air density
- Turbine Data: rotor speed, blade pitch angle, power curve, status logs, historical output
- External Data: NWP models, satellite data, terrain data

Data Processing:

- Clean missing/noisy data
- Timestamp alignment
- Feature engineering (wind shear, gust factors)
- Normalization

Prediction Engine:

- ML Models: Random Forest, Gradient Boosting
- Deep Learning: LSTM, CNN-LSTM
- Forecast horizons: short-term, day-ahead, week-ahead

Output & Visualization:

- Real-time predictions
- Confidence intervals
- Alerts & dashboards
- API integration

4. Non-Functional Requirements

- Accuracy: <5–8% MAPE
- Real-time performance (<5 sec)
- 99.9% uptime
- Secure data encryption

5. Next-Generation Features

- AI self-learning & anomaly detection
- Digital twin simulation
- Edge computing
- Hybrid forecasting

6. System Architecture

Layers: Data → Processing → AI → Application → Integration

7. Technology Stack

- Python, Spark, Kafka
- TensorFlow, PyTorch, Scikit-learn
- Cloud: AWS/Azure/GCP
- Edge: IoT devices

8. Evaluation Metrics

- MAPE, RMSE, bias, latency

9. Risks & Challenges

- Weather variability
- Sensor failures
- Terrain complexity
- Model drift

10. Future Scope

- Smart grid integration
- Carbon credit optimization
- Autonomous wind farms
- Climate modeling