**Project Design Phase**

**Solution Architecture**

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| --- | --- |
| Date | 15 February 2026 |
| Team ID | LTVIP2026TMIDS67435 |
| Project Name | Weather-Based Prediction Of Wind Turbine Energy Output**:** *A Next-Generation Approach To Renewable Energy Management* |
| Maximum Marks | 4 Marks |

**Goals of the Solution Architecture:**

The solution architecture for the Weather-Based Wind Turbine Energy Prediction System is a cloud-native AI-driven renewable energy forecasting platform.

It integrates weather APIs, turbine sensor data, machine learning models, and interactive dashboards to provide accurate wind energy output predictions and support grid stability.

The solution connects: Weather Data Providers, Wind Turbine SCADA Systems, Grid Operators, Energy Storage Systems, Government Energy Boards.

through a scalable cloud-based architecture with real-time analytics and predictive intelligence.

**Goals of the Solution Architecture:**

**1 Business Goals**

* **BG1 – Improve Forecast Accuracy**:  
  Achieve ≥ 85% prediction accuracy for wind energy output**.**
* **BG2 – Grid Stability:**Reduce unexpected power fluctuations by 30%.
* **BG3 – Operational Efficiency:**Optimize turbine utilization and energy storage systems.
* **BG4 – Sustainability Compliance:**Support renewable energy targets and carbon reduction goals.

**2 Product Goals**

* + **PG1 – Real-Time Monitoring:**  
    Provide live dashboard with weather and energy output metrics.
  + **PG2 – Predictive Intelligence:**  
    Generate hourly, daily, and weekly forecasts.
  + **PG3 – Smart Alerts:**  
    Provide overload and low-production warnings.
  + **PG4 – Historical Analysis:**  
    Allow comparison of predicted vs actual performance.

**3 Technical Goals**

* **TG1 – Cloud Scalability:**  
  Support multiple wind farms across regions.
* **TG2 – High Availability:**  
  Ensure ≥ 99% uptime with auto-scaling and failover.
* **TG3 – Security:**  
  Encrypt turbine and weather data using TLS and AES-256.
* **TG4 – Observability:**  
  Enable logging, monitoring, and model performance tracking.
* **TG5 – Extensibility:**  
  Allow future integration with solar and hybrid systems.

**4 Scope (Phase 2 – Project Design)**

**In Scope:**

* Weather API integration
* Machine learning prediction engine
* Data preprocessing module
* Dashboard visualization
* Alerts & notification system
* Model evaluation metrics

**Out of Scope (Phase 2):**

* Advanced energy trading marketplace
* AI-based dynamic pricing
* Cross-country renewable energy grid trading

**5 Stakeholders & Personas**

 Wind Farm Operators

 Grid Managers

 Energy Storage Managers

 Renewable Energy Analysts

 Government Energy Regulators

 Data Scientists

**6) High‑Level Architecture (Overview)**

**[ Weather API ] [ Turbine SCADA System ]**

**│ │**

**└──────────────► Data Collection Layer ◄──────────────┘**

**│**

**Data Preprocessing**

**│**

**Machine Learning Layer**

**(Random Forest / LSTM Models)**

**│**

**Prediction Output Engine**

**│**

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**│ │ │ │**

**Dashboard UI Alert System Storage Optimizer Reports**

**│**

**Grid Operators**

**Key Patterns:**

* Microservices Architecture
* Event-driven data processing
* API Gateway
* Cloud-native deployment
* Modular ML pipeline

**7) Core Components (Responsibilities)**

**Data Collection Module**

Collects weather API data and turbine sensor data.

**Data Preprocessing Module**

Cleans, normalizes, and prepares data for training.

**ML Prediction Engine**

Uses regression and time-series models for forecasting.

**Dashboard Module**

Displays visual charts of energy predictions.

**Alert Module**

Triggers warnings for overload or low production.

**Storage Optimization Module**

Suggests efficient battery charging cycles.

**8) Data Flow Summary**

1. Weather data is fetched from API.
2. Turbine performance data is collected.
3. Data is cleaned and stored in database.
4. ML model generates energy forecast.
5. Forecast results are displayed on dashboard.
6. Alerts are generated if thresholds are crossed.

**9) Technology Choices**

**Frontend:**

* React.js / Angular
* Chart.js / D3.js

**Backend:**

* Python (Flask / FastAPI)
* REST APIs

**Machine Learning:**

* Scikit-learn
* TensorFlow / Keras
* Pandas / NumPy

**Database:**

* PostgreSQL
* MongoDB
* Redis Cache

**Infrastructure:**

* AWS / Azure / GCP
* Docker + Kubernetes
* NGINX

**10) Security & Compliance**

* TLS encryption for API communication
* AES-256 encryption for stored data
* Role-Based Access Control (RBAC)
* Secure API keys management
* Compliance with renewable energy regulatory reporting

**11) Non-Functional Targets**

Availability ≥ 99%

Prediction response time ≤ 5 seconds

Forecast Accuracy ≥ 85%

Support 5,000 concurrent users

Cloud auto-scaling enabled

**12) Success Metrics**

* Reduced power imbalance events
* Improved forecast accuracy
* Increased renewable integration rate
* Reduced energy storage wastage
* Improved stakeholder satisfaction

**13) Risks & Mitigations**

Weather variability → Continuous model retraining

Data inconsistency → Automated validation checks

System overload → Cloud auto-scaling

Security threats → Encryption & firewall protection

**14) Roadmap**

MVP → Basic prediction + dashboard

Version 1 → Alerts + storage optimization

Version 2 → Hybrid renewable forecasting (wind + solar)

Version 3 → AI-based smart grid integration

**15) Glossary**

SCADA – Supervisory Control and Data Acquisition

LSTM – Long Short-Term Memory (Deep Learning model)

RMSE – Root Mean Square Error

MAE – Mean Absolute Error

RBAC – Role-Based Access Control

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