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Recent Trends and Applications of AI in Renewable Energy Technologies

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20 August 2026

Presenter: Dr. Shezan Arefin

Research Faculty, Adjunct Associate Professor at Laval University, Associate Professor at Northern Border University, Adjunct Faculty at Murdoch University

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About the presenter

Dr. Shezan Arefin

Bio: Dr. Shezan Arefin is an expert in Renewable Energy Integration, Power System Analysis, Power Transmission/Distribution systems, and Power Quality Analysis. He **ranked in the world's Top 2% Scientists (back-to-back 4 years; 2022-2025) as listed by Elsevier (in collaboration with Stanford University)**. He has been working for the Engineering Institute of Technology, Australia, as a Research Supervisor and Unit Coordinator. Moreover, he is currently working as an Adjunct Associate Professor in the Electrical Engineering Department at Laval University, Canada, and as an Adjunct Senior Lecturer at the School of Energy and Engineering, Murdoch University, Australia. Moreover, previously he was working as a grid connection and renewable energy consultant for Doosan GridTech Inc., Melbourne office, Australia and for Elecnor Australia as a Power System consultant. He completed his PhD degree in Electrical and Electronic Engineering from RMIT University, Melbourne, Australia. He received his Master of Engineering degree from the University of Malaya. Moreover, he received his Bachelor of Engineering degree in Electrical Engineering and Automation from Shenyang University of Chemical Technology, China. His research interests and technical expertise lie in Microgrid design and analysis, Hybrid Renewable Energy Systems, Power System Modelling and Analysis, grid connection studies, feasibility studies, Solar Energy, Wind Energy, Optimization and AI/Machine Learning-based Microgrid assessment, Control Systems, Power Electronics, BESS Monitoring and Control techniques, and Energy Economics, etc.

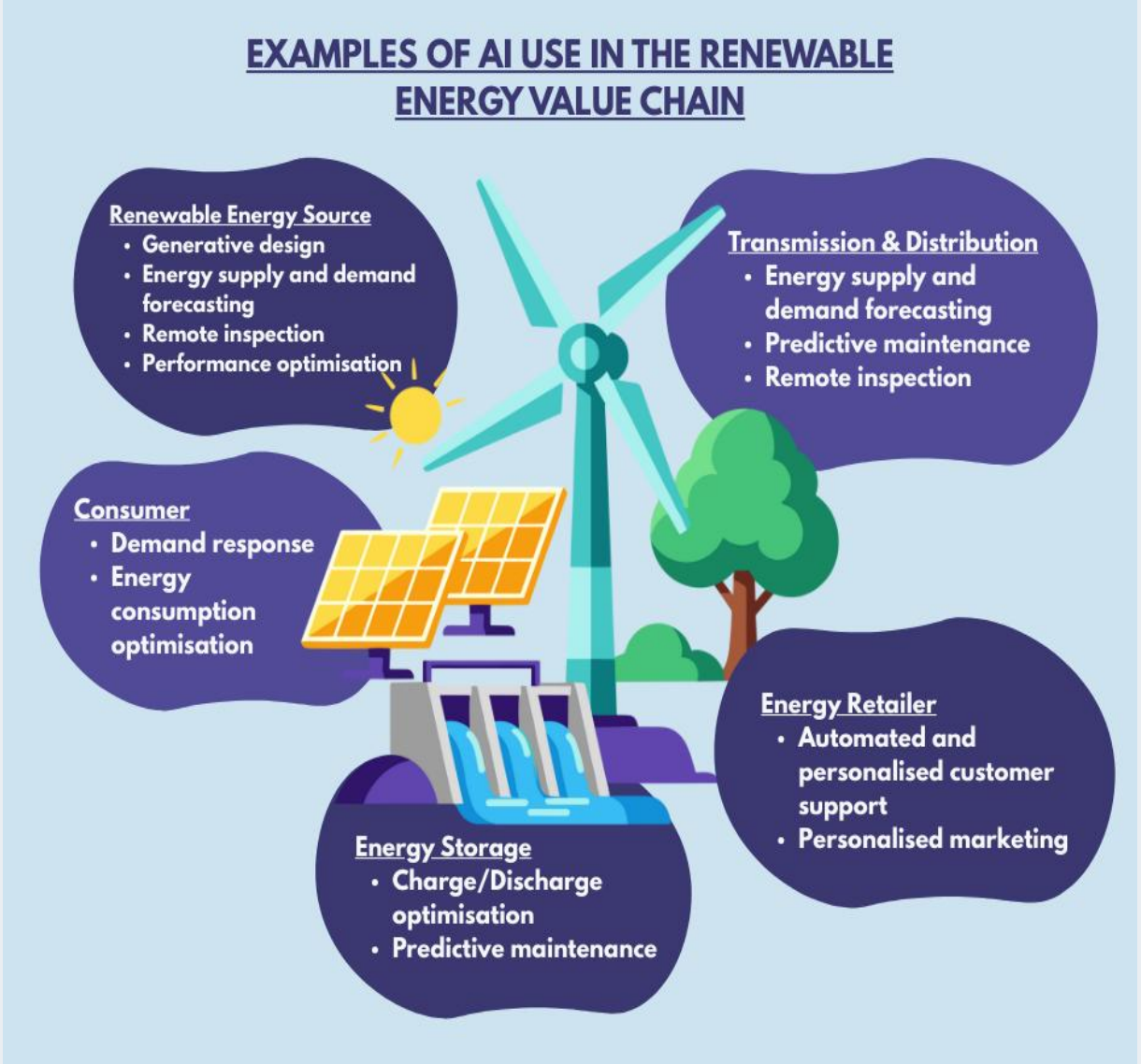
Agenda

1.	Introduction to AI in Renewable Energy
2.	AI in Solar Energy
3.	AI in Wind Energy
4.	AI in Smart Grids & Grid Integration
5.	AI in Energy Storage Systems
6.	Emerging AI Techniques
7.	Case Studies
8.	Challenges & Future Outlook

1. Introduction

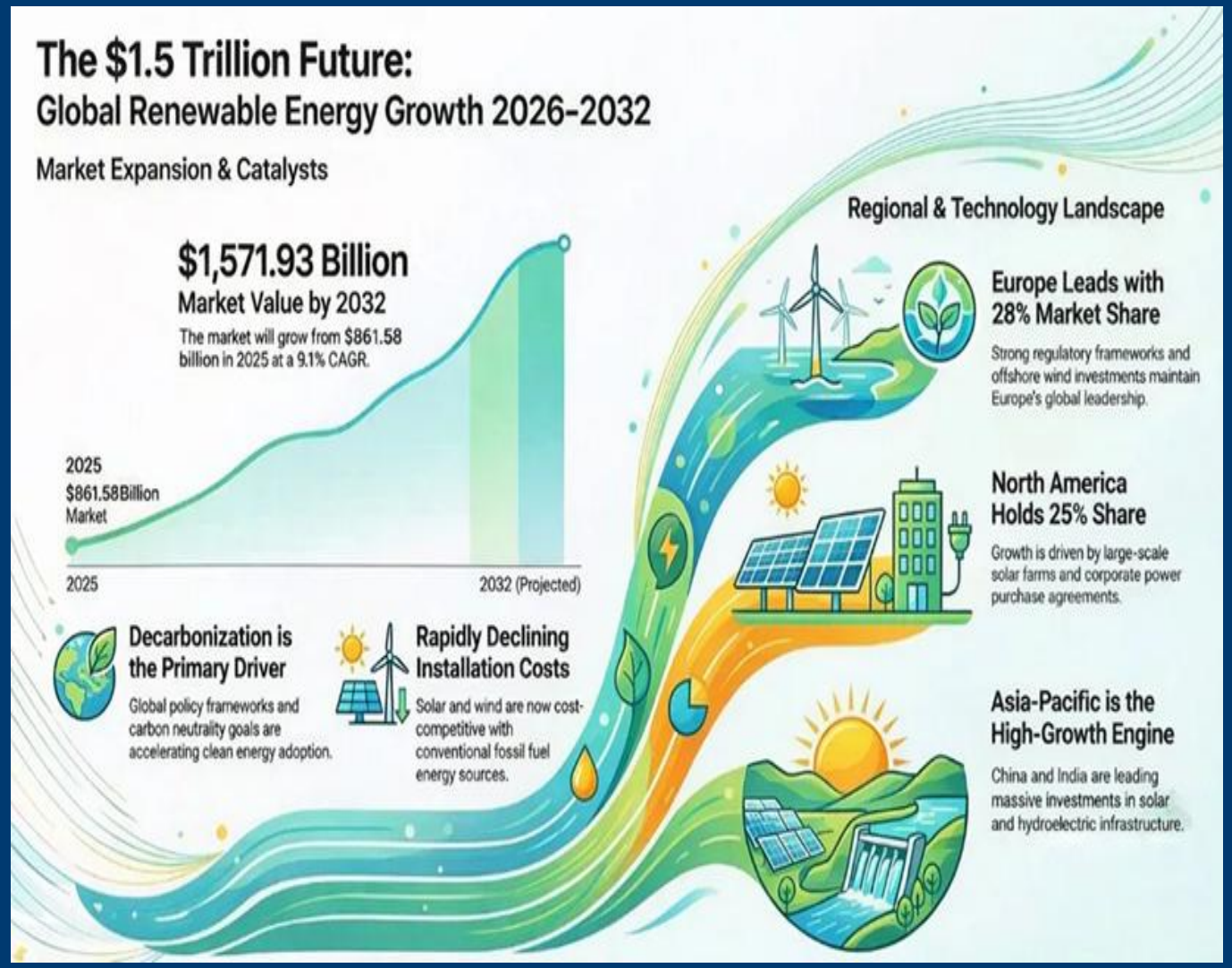
Why AI Matters for Renewable Energy

- Renewable output is inherently variable, driven by weather, irradiance, and wind speed
- AI models capture nonlinear patterns that classical statistical methods miss
- Improves forecasting accuracy, reduces curtailment, and lowers balancing costs
- Enables predictive maintenance, cutting downtime and O&M expenditure
- Supports real-time optimization across generation, storage, and grid operations



The Global Renewable Energy Landscape in 2026

- Renewables account for a growing share of new global power capacity additions
- Solar PV and wind remain the fastest-growing generation sources worldwide
- Grid operators increasingly rely on data-driven tools to manage variability
- Investment in AI-enabled energy analytics platforms is accelerating
- Policy frameworks increasingly mandate smart grid and forecasting standards



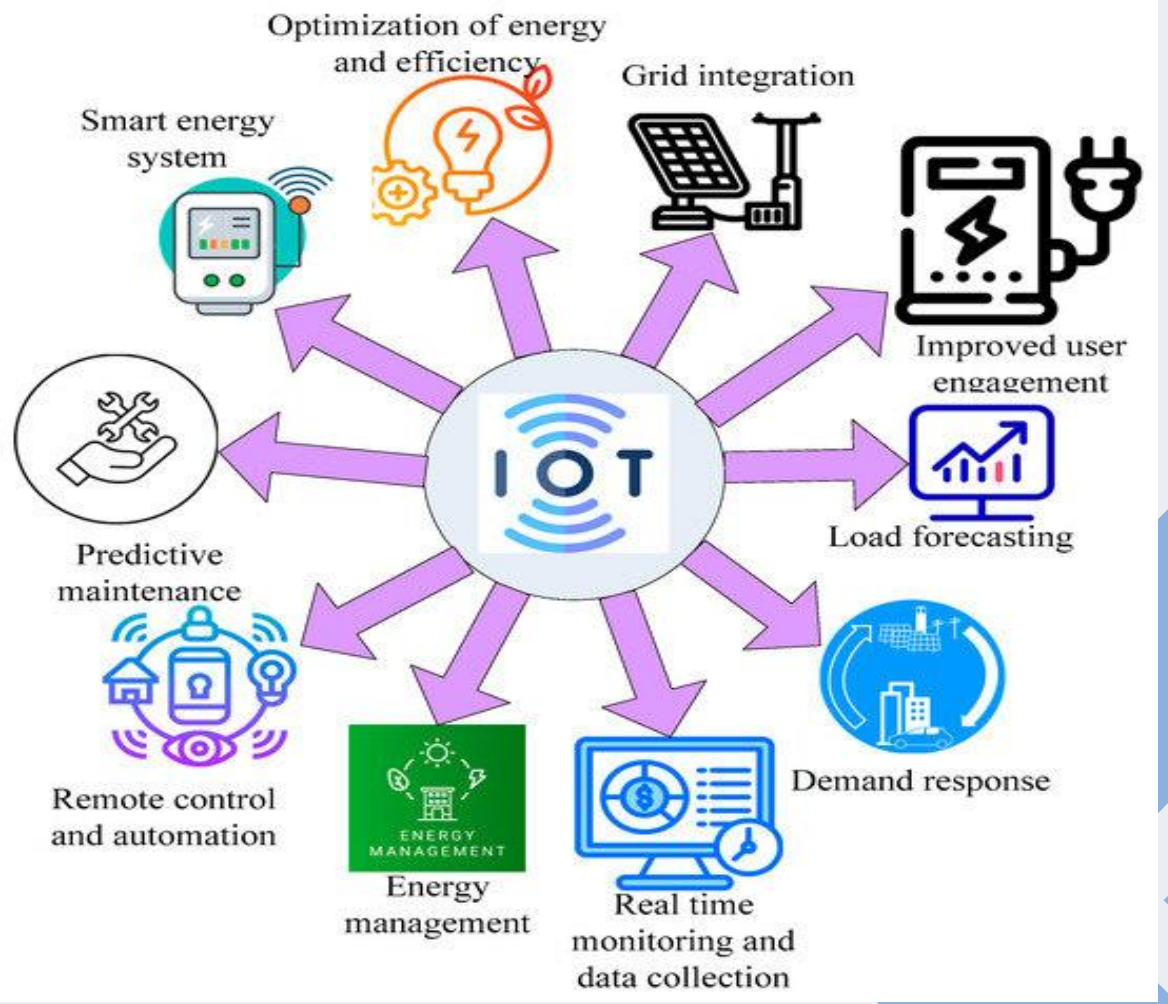
Core AI Techniques Powering Modern Energy Systems

Classical Machine Learning

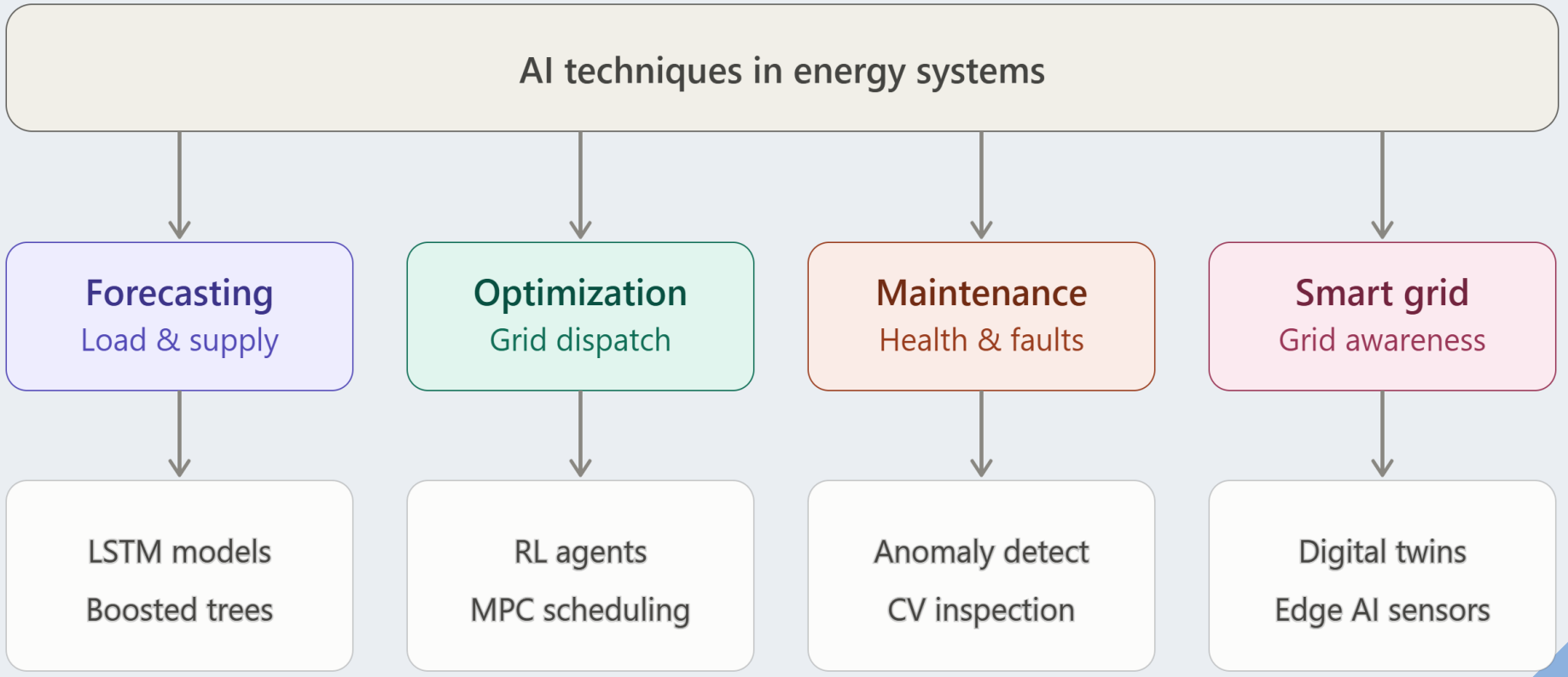
- Regression models for power curve and yield estimation
- Random forests and gradient boosting for short-term forecasting
- Support vector machines for fault classification
- Clustering for anomaly and pattern detection

Deep Learning & Reinforcement Learning

- Convolutional neural networks for image-based defect detection
- LSTM/GRU and transformer models for time-series forecasting
- Reinforcement learning for real-time control and dispatch
- Graph neural networks for grid topology analysis



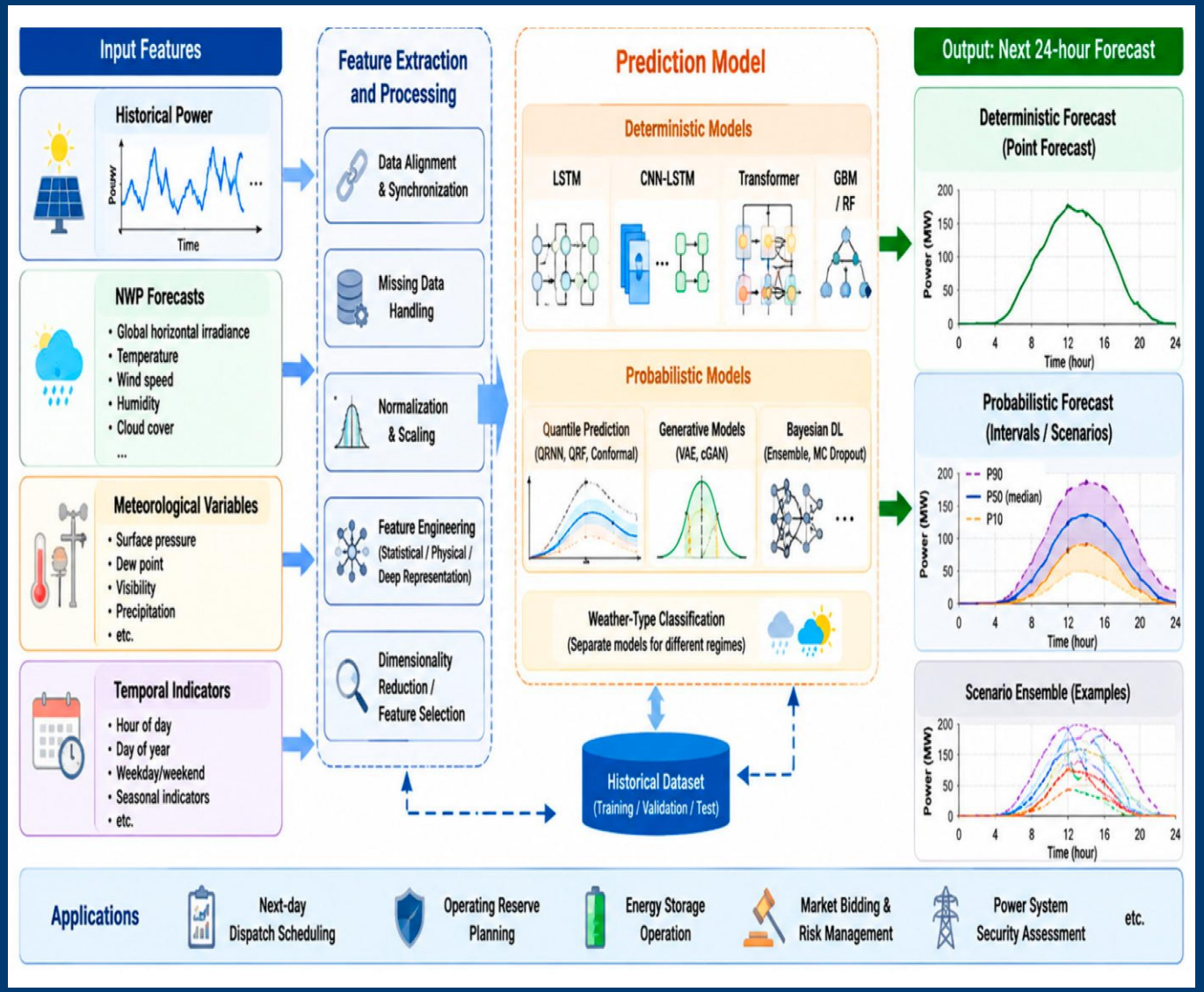
Core AI Techniques Powering Modern Energy Systems



2. AI in Solar Energy

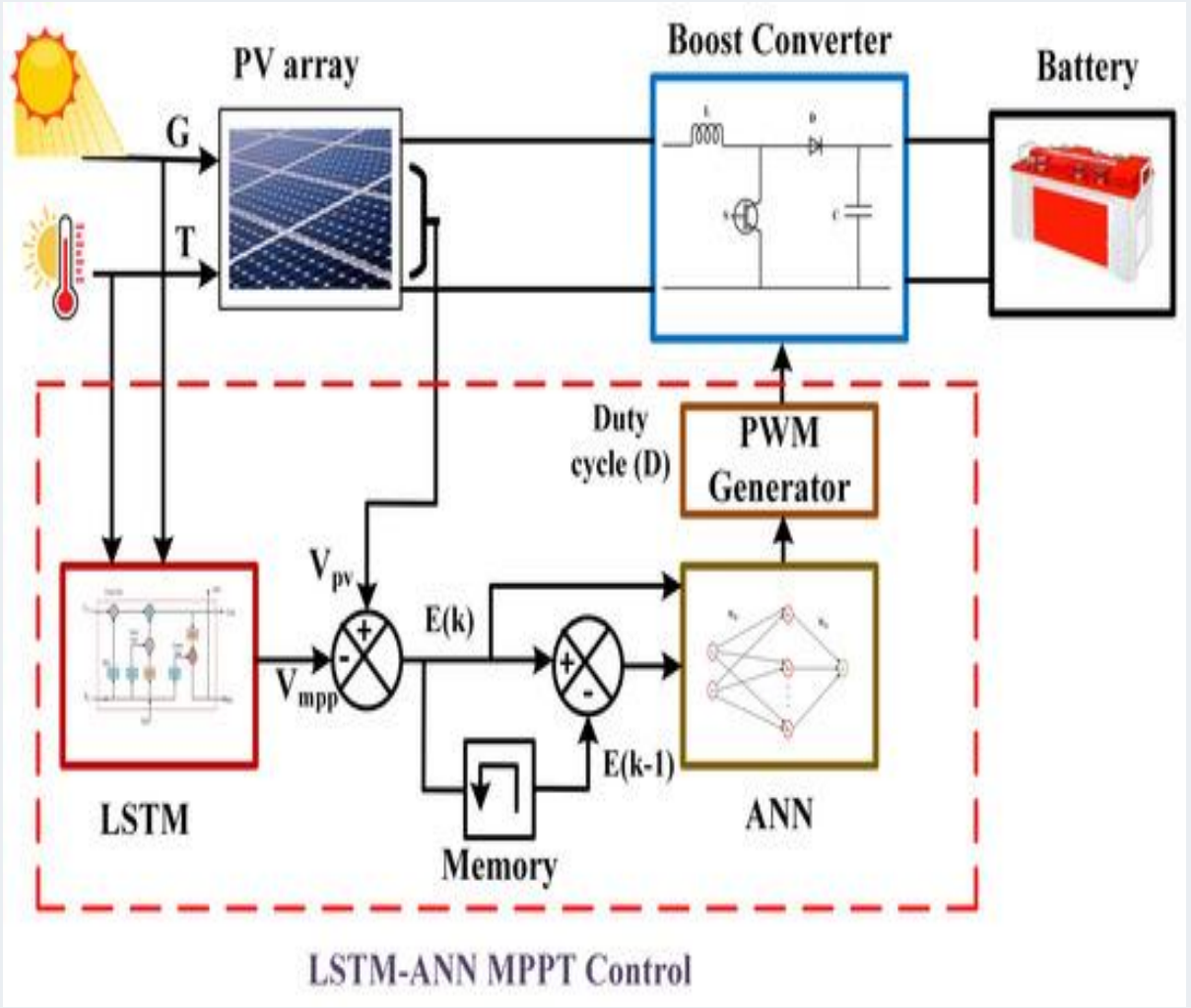
AI-Based Solar Irradiance and Power Forecasting

- Combines satellite imagery, sky-camera data, and numerical weather prediction
- LSTM and transformer models forecast irradiance minutes to days ahead
- Improves day-ahead market bidding and reduces imbalance penalties
- Hybrid physical-AI models outperform purely statistical approaches
- Enables better scheduling of backup generation and storage dispatch



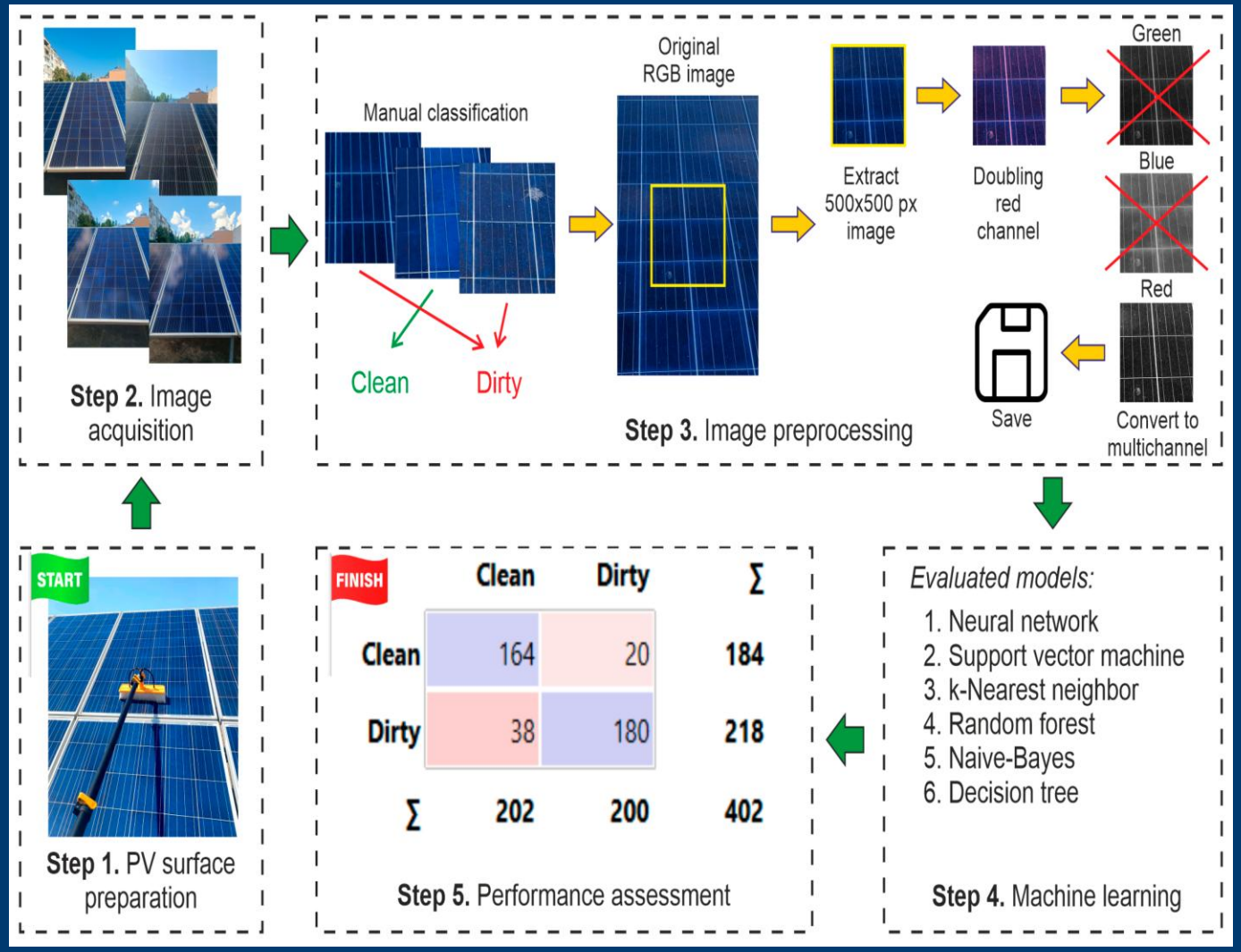
Maximum Power Point Tracking (MPPT) with AI

- Traditional MPPT (P&O, Incremental Conductance) struggles under partial shading
- Neural network and fuzzy-logic controllers adapt tracking in real time
- Reinforcement learning-based MPPT improves convergence speed and accuracy
- Reduces power losses from rapidly changing irradiance conditions
- Enhances overall inverter efficiency across varying operating conditions



Computer Vision for Solar Panel Fault and Soiling Detection

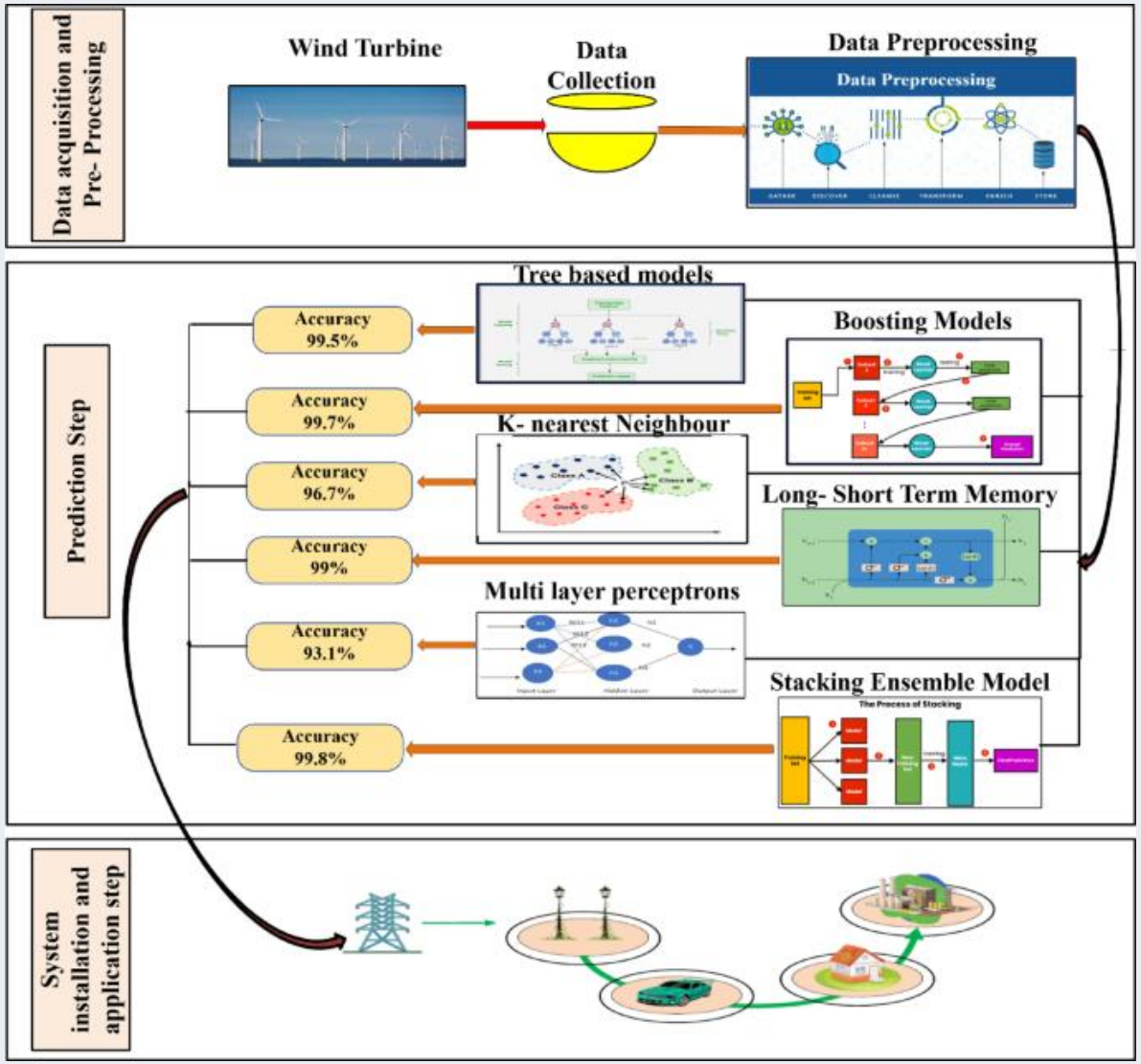
- CNN-based image classification identifies cracks, hotspots, and delamination
- Drone and thermal imaging combined with deep learning speeds up inspection
- Soiling detection models estimate cleaning schedules and energy loss
- Automated defect detection reduces manual inspection costs significantly
- Supports predictive scheduling of maintenance crews and equipment



3. AI in Wind Energy

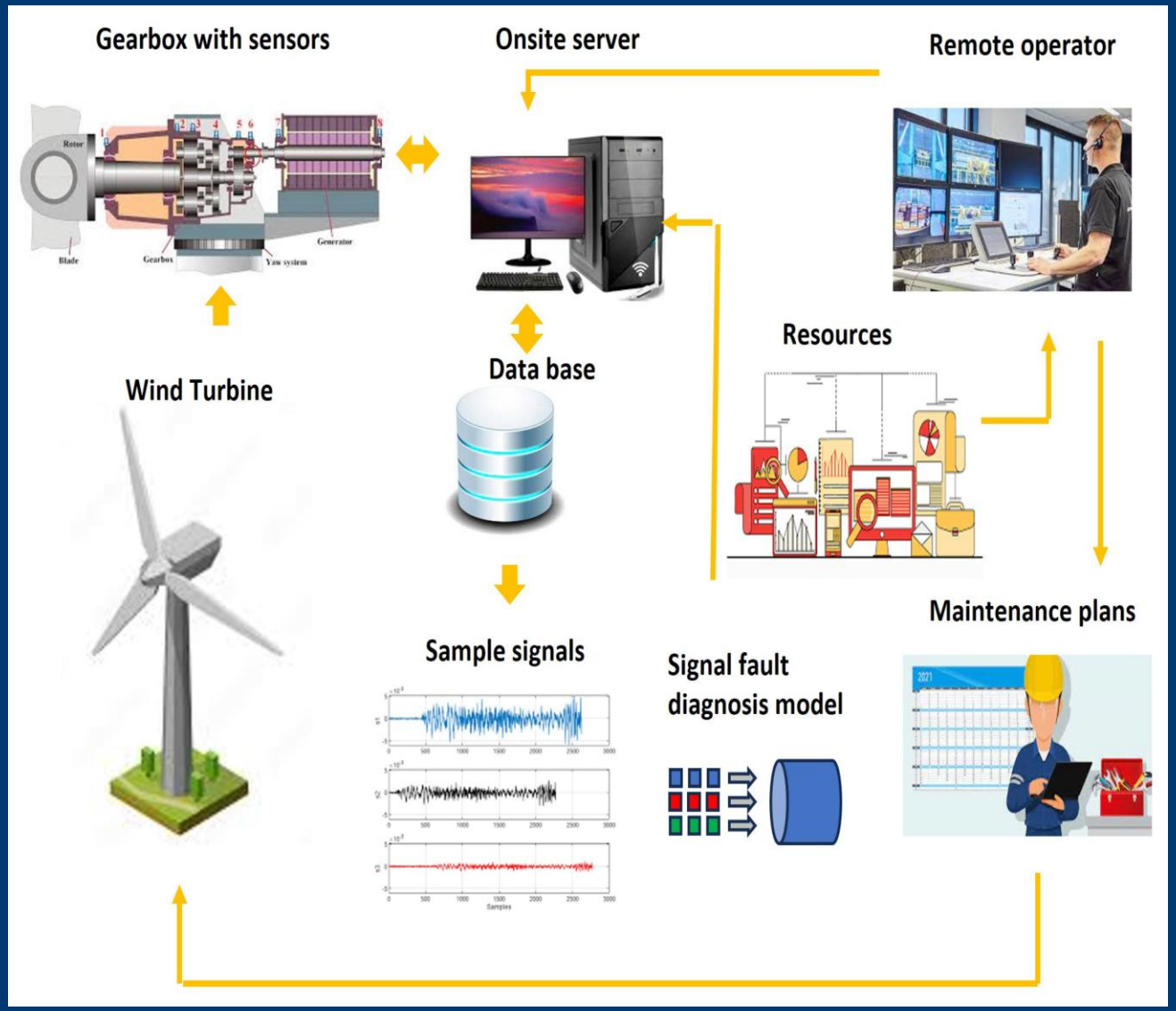
Wind Power Forecasting Models

- Short-term forecasting relies on SCADA data and machine learning regressors
- LSTM and hybrid CNN-LSTM models capture temporal wind speed patterns
- Ensemble methods combine multiple models to improve forecast robustness
- Accurate forecasts reduce reserve capacity requirements and balancing costs
- Enables improved participation in day-ahead and intraday energy markets



AI-Driven Predictive Maintenance for Wind Turbines

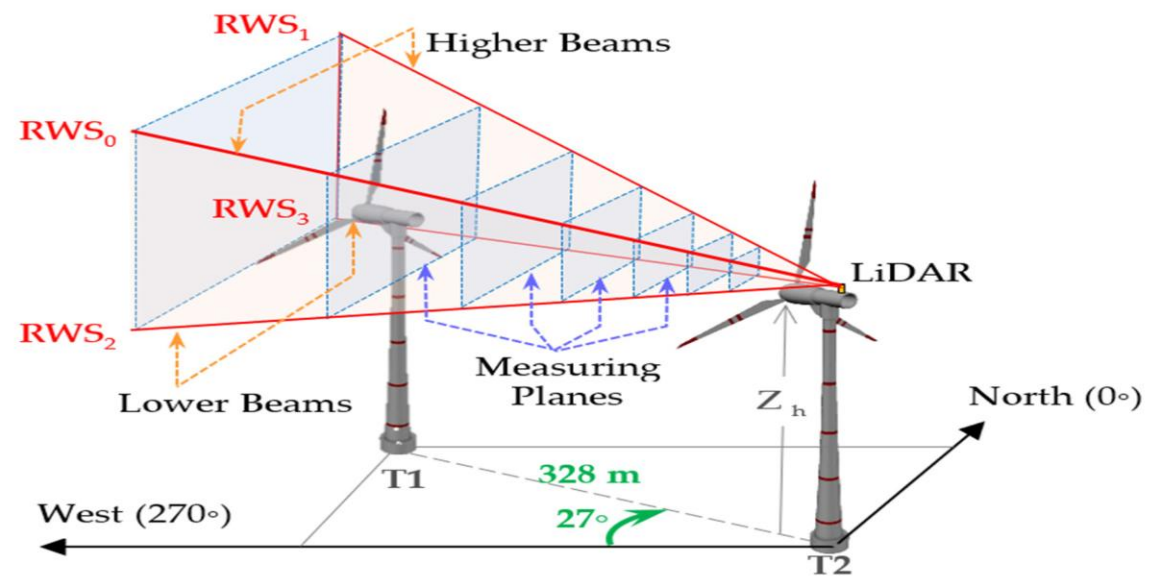
- SCADA and vibration sensor data feed anomaly detection algorithms
- Machine learning predicts gearbox, bearing, and blade failures in advance
- Reduces unplanned downtime and extends component service life
- Condition-based maintenance replaces fixed-interval maintenance schedules
- Digital twin models simulate turbine health under varying load conditions



Optimizing Blade Design and Wake Steering with AI

Blade & Aerodynamic Design

- Surrogate ML models accelerate CFD simulations
- Generative design explores blade geometries for efficiency
- AI-assisted structural optimization reduces material and weight
- Speeds up design iteration versus CFD-only workflows



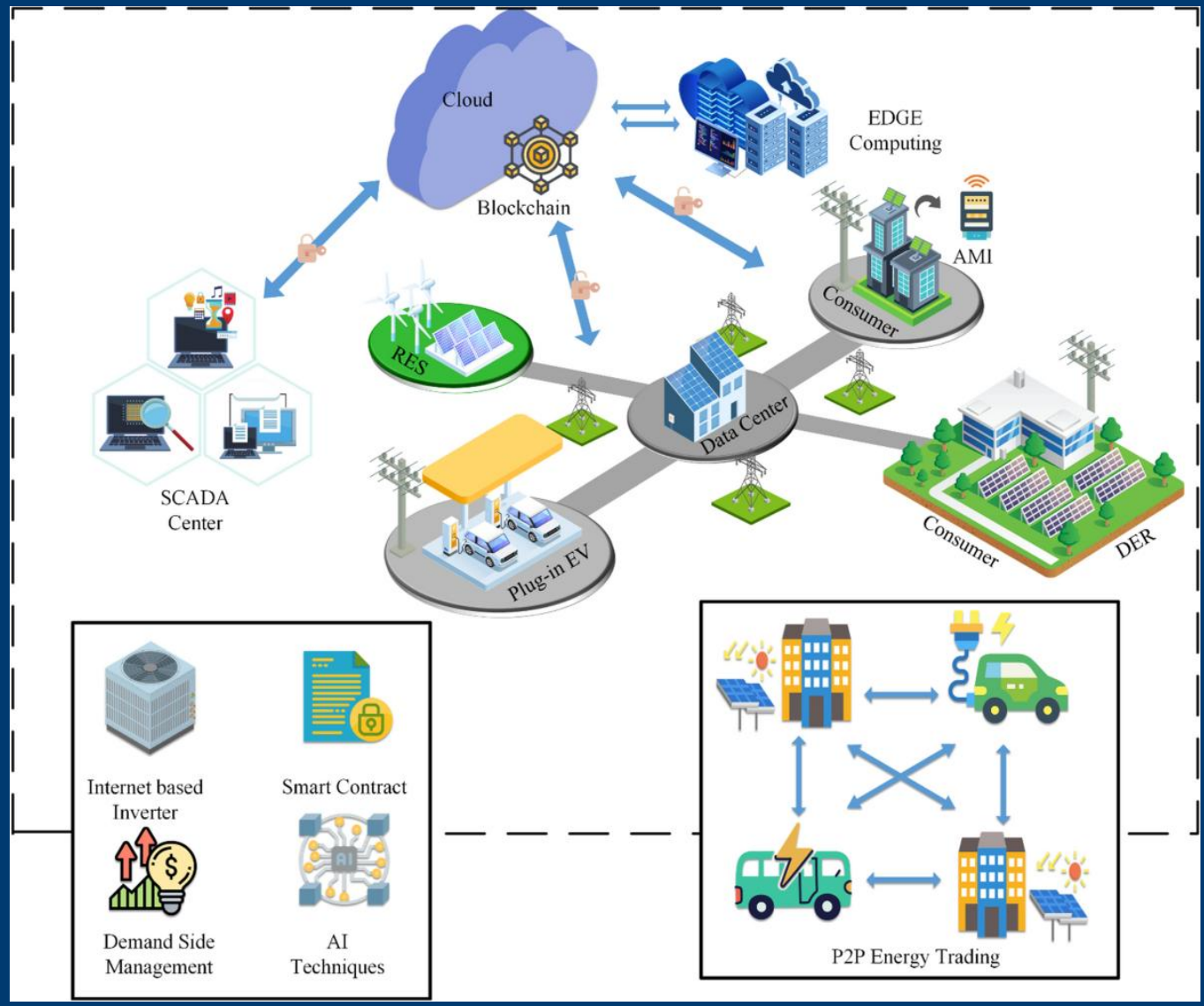
Wake Steering & Farm-Level Control

- Reinforcement learning coordinates yaw angles across turbines
- Reduces wake losses and increases farm energy yield
- Farm-level AI control balances loads to reduce fatigue
- Real-time adaptation to changing wind direction and speed

4. AI in Smart Grids & Grid Integration

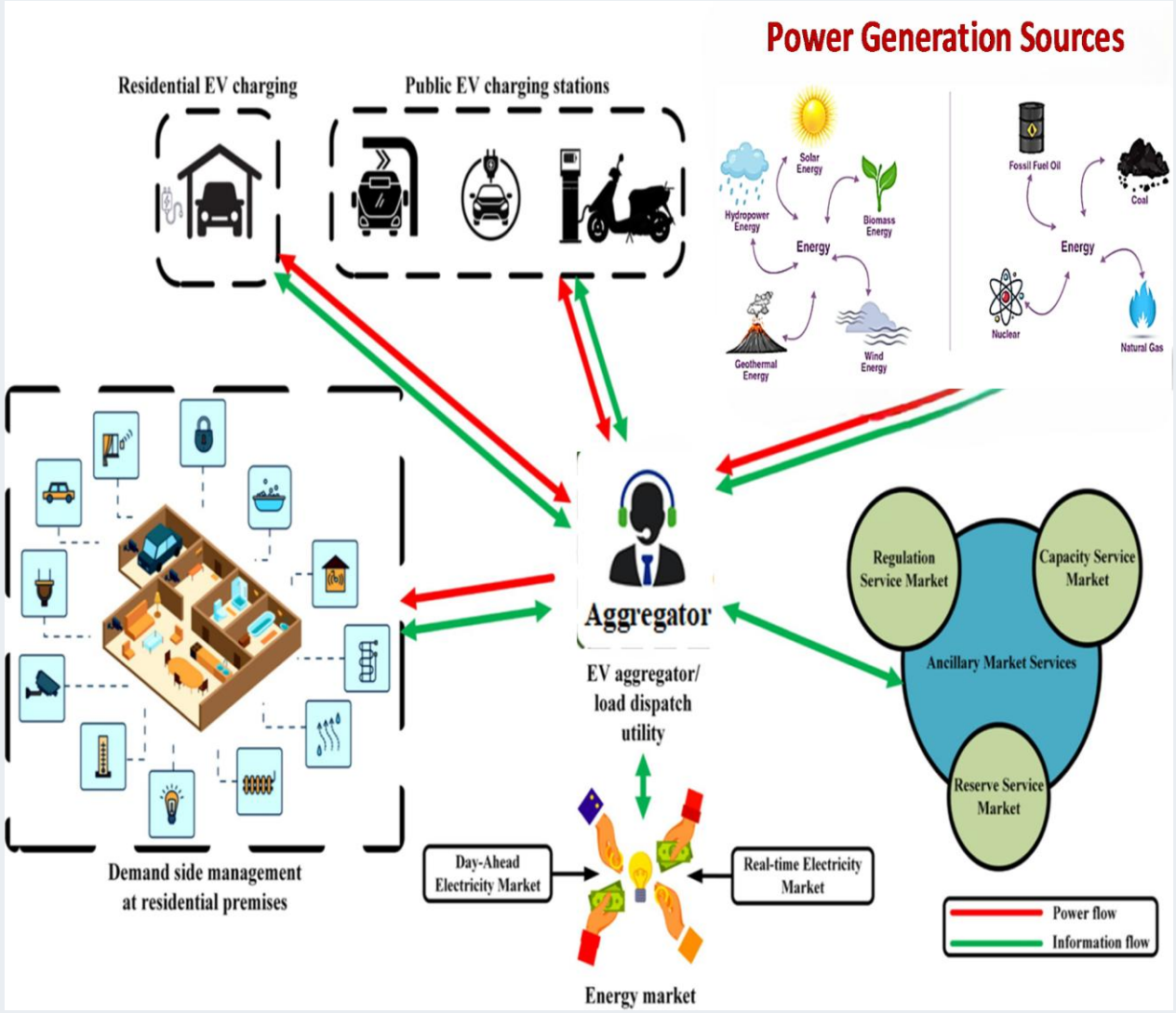
Smart Grid Management and Load Forecasting

- AI models integrate weather, historical load, and behavioral data
- Short- and long-term load forecasting supports capacity planning
- Enables dynamic pricing and improved renewable energy integration
- Reduces forecasting error compared to traditional statistical methods
- Supports real-time balancing of supply and demand across the grid



AI-Based Demand Response Optimization

- Machine learning identifies flexible loads suitable for demand response
- Predicts consumer response to price signals and incentive programs
- Optimizes scheduling of controllable loads such as EV charging and HVAC
- Improves grid reliability during peak demand and renewable shortfalls
- Enhances customer engagement through personalized recommendations



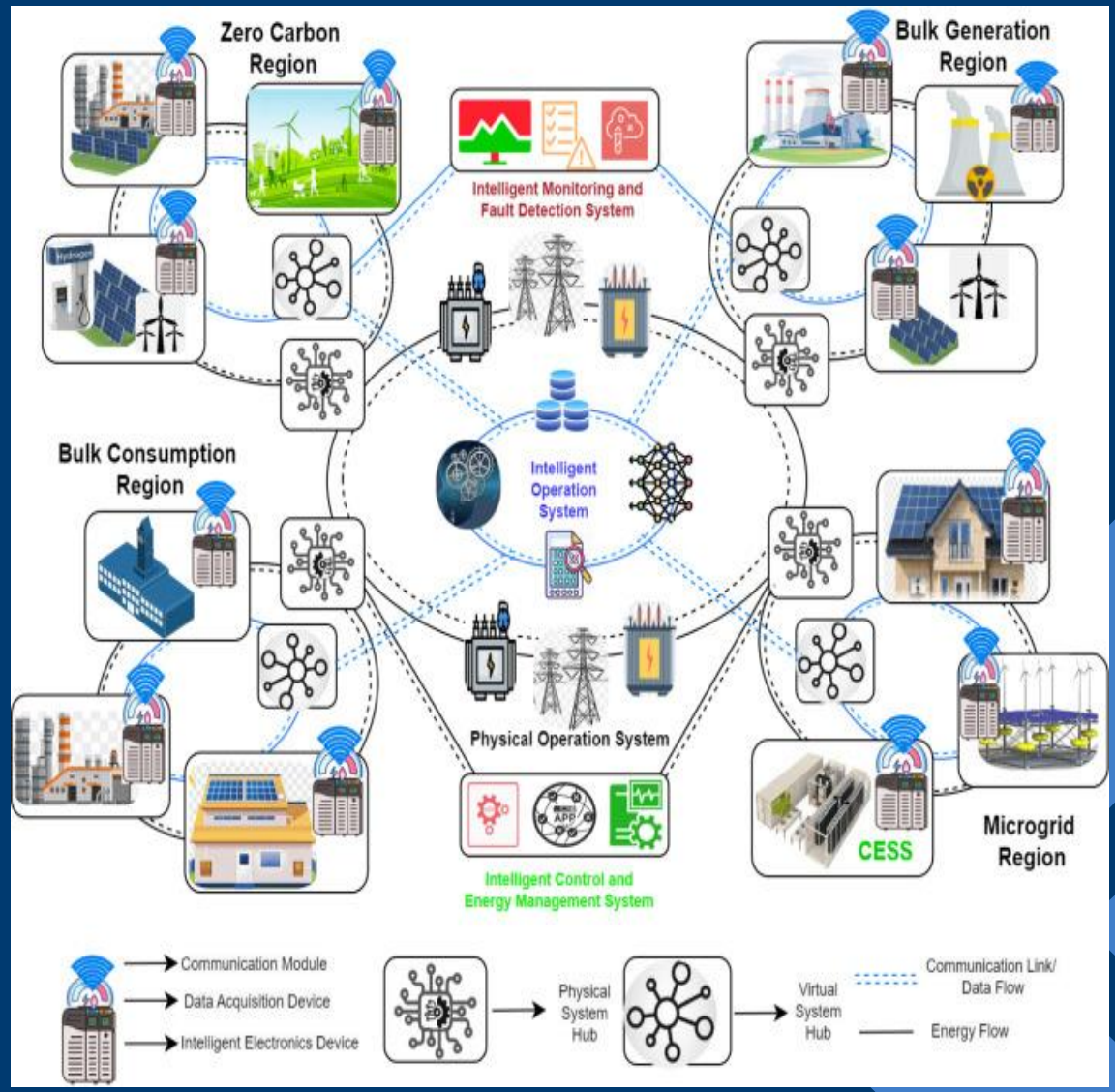
AI for Fault Detection and Grid Stability

Fault Detection & Diagnosis

- Machine learning classifies fault types from sensor and PMU data
- Deep learning enables faster fault localization than rule-based systems
- Reduces outage duration through automated diagnostic support
- Supports predictive detection of equipment degradation

Voltage & Frequency Stability

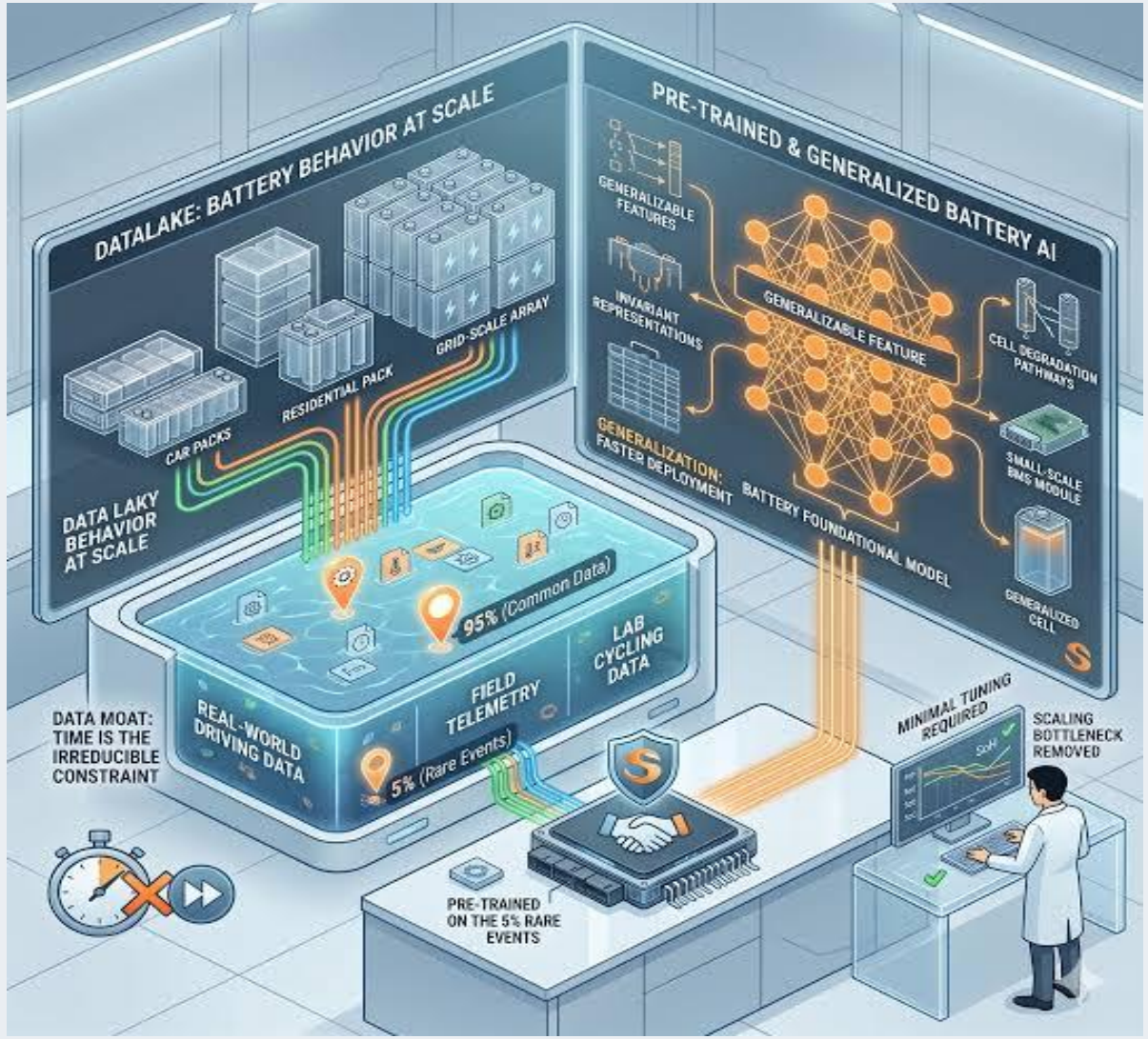
- AI-based controllers respond to frequency deviations in near real time
- Reinforcement learning optimizes reactive power and voltage regulation
- Supports stability with high shares of variable renewable generation
- Improves coordination of distributed energy resources



5. AI in Energy Storage Systems

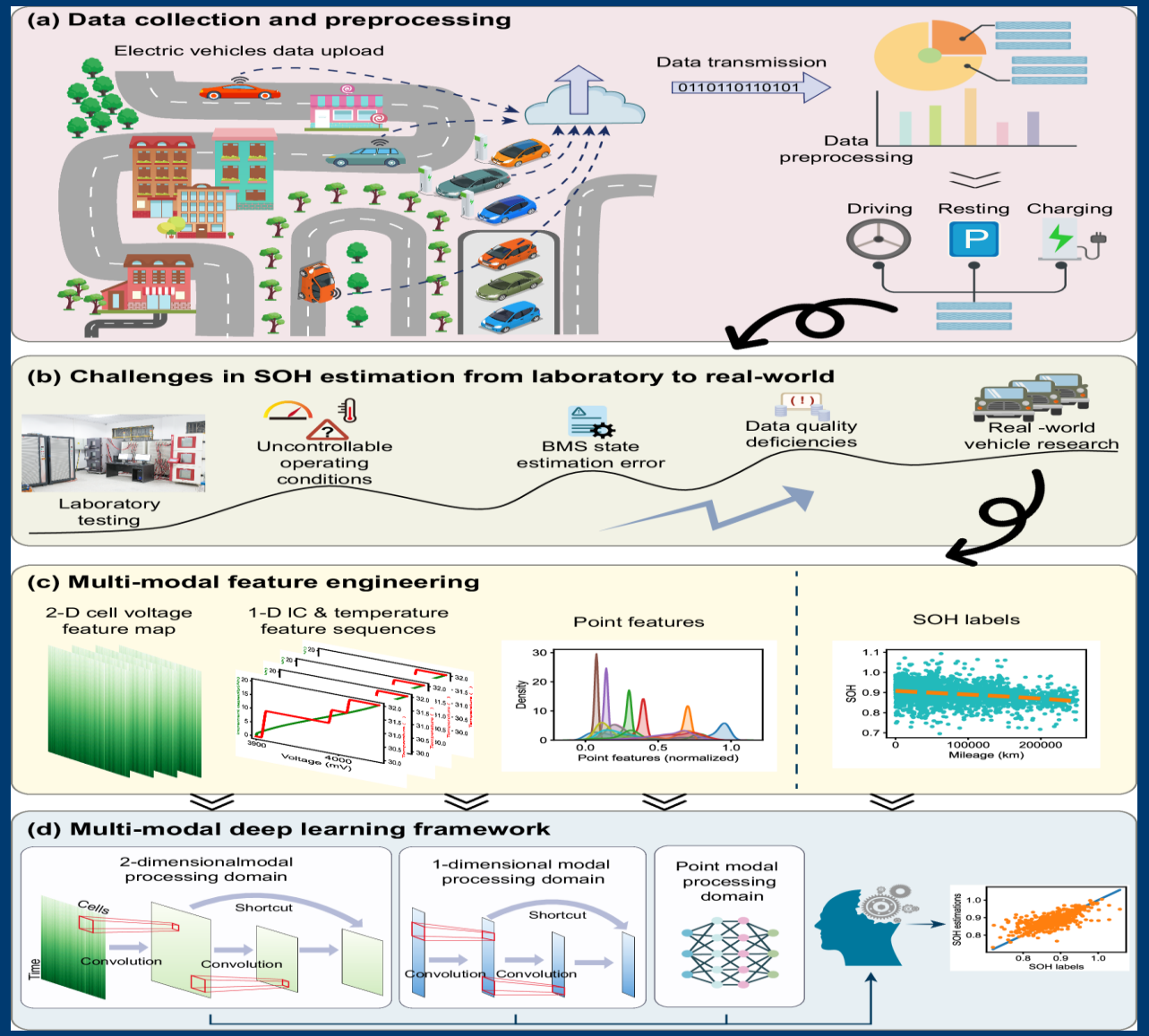
AI-Driven Battery Management Systems (BMS)

- Machine learning models estimate battery degradation and remaining life
- AI optimizes charge/discharge cycles to extend battery lifespan
- Improves thermal management through predictive temperature modeling
- Enables adaptive control strategies for hybrid storage systems
- Supports second-life battery assessment for stationary storage use



State-of-Charge and State-of-Health Estimation using ML

- Traditional Coulomb counting suffers from cumulative estimation errors
- Neural networks and Kalman-filter hybrids improve SoC accuracy
- ML models estimate SoH from voltage, current, and temperature patterns
- Improves reliability of storage dispatch and grid service commitments
- Reduces risk of premature battery replacement or unexpected failure



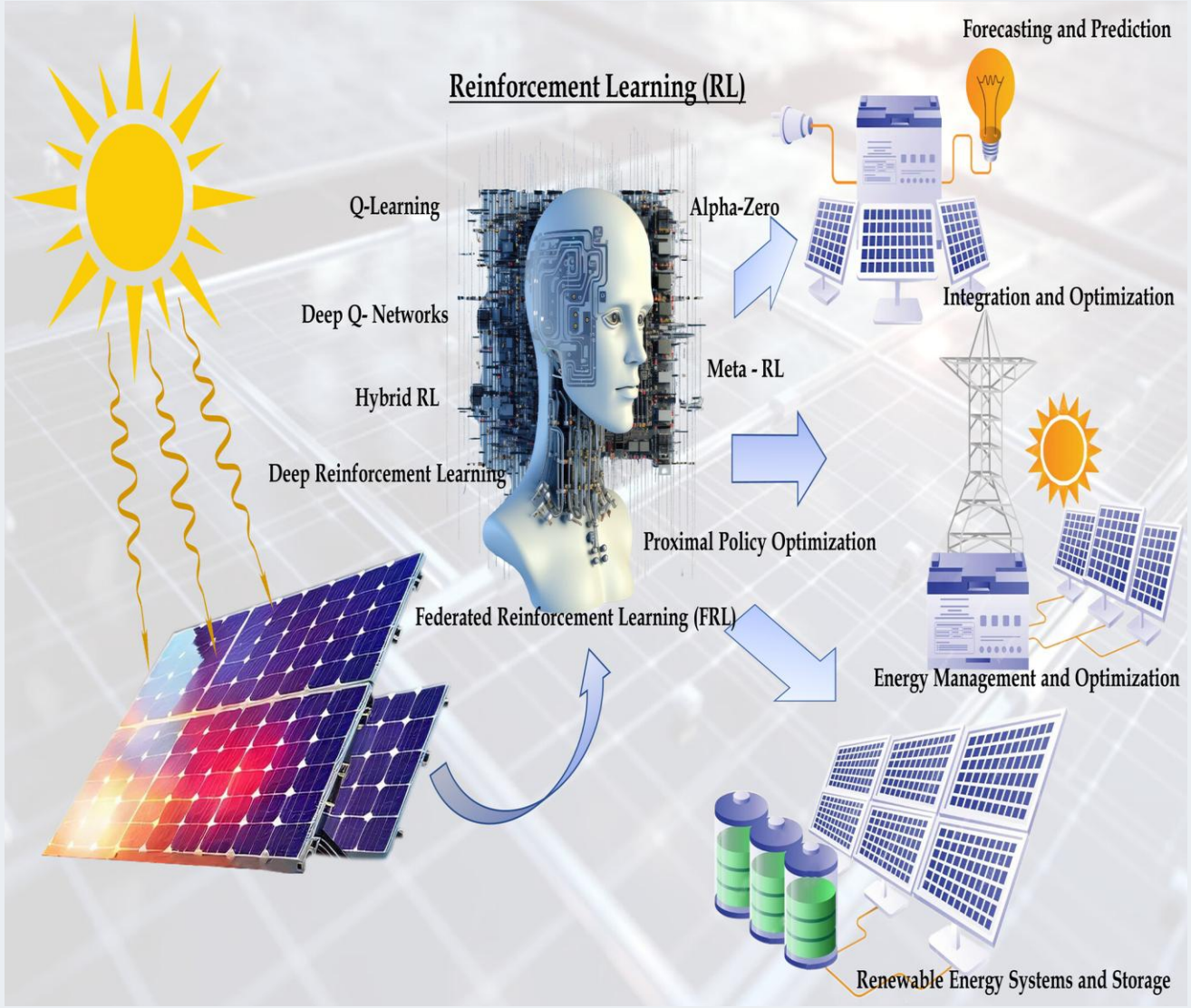
6. Emerging AI Techniques

Digital Twins for Renewable Energy Assets

- Virtual replicas combine sensor data with physics-based and AI models
- Enables simulation of turbine, panel, or grid behavior under varying conditions
- Supports predictive maintenance and performance optimization
- Reduces need for costly physical prototyping and testing
- Facilitates scenario planning for asset lifecycle management

Reinforcement Learning for Energy System Optimization

- RL agents learn optimal control policies through trial-and-error interaction
- Applied to microgrid energy management and battery dispatch scheduling
- Optimizes multi-objective trade-offs between cost, emissions, and reliability
- Adapts to changing system conditions without explicit reprogramming
- Increasingly combined with digital twins for safe policy training



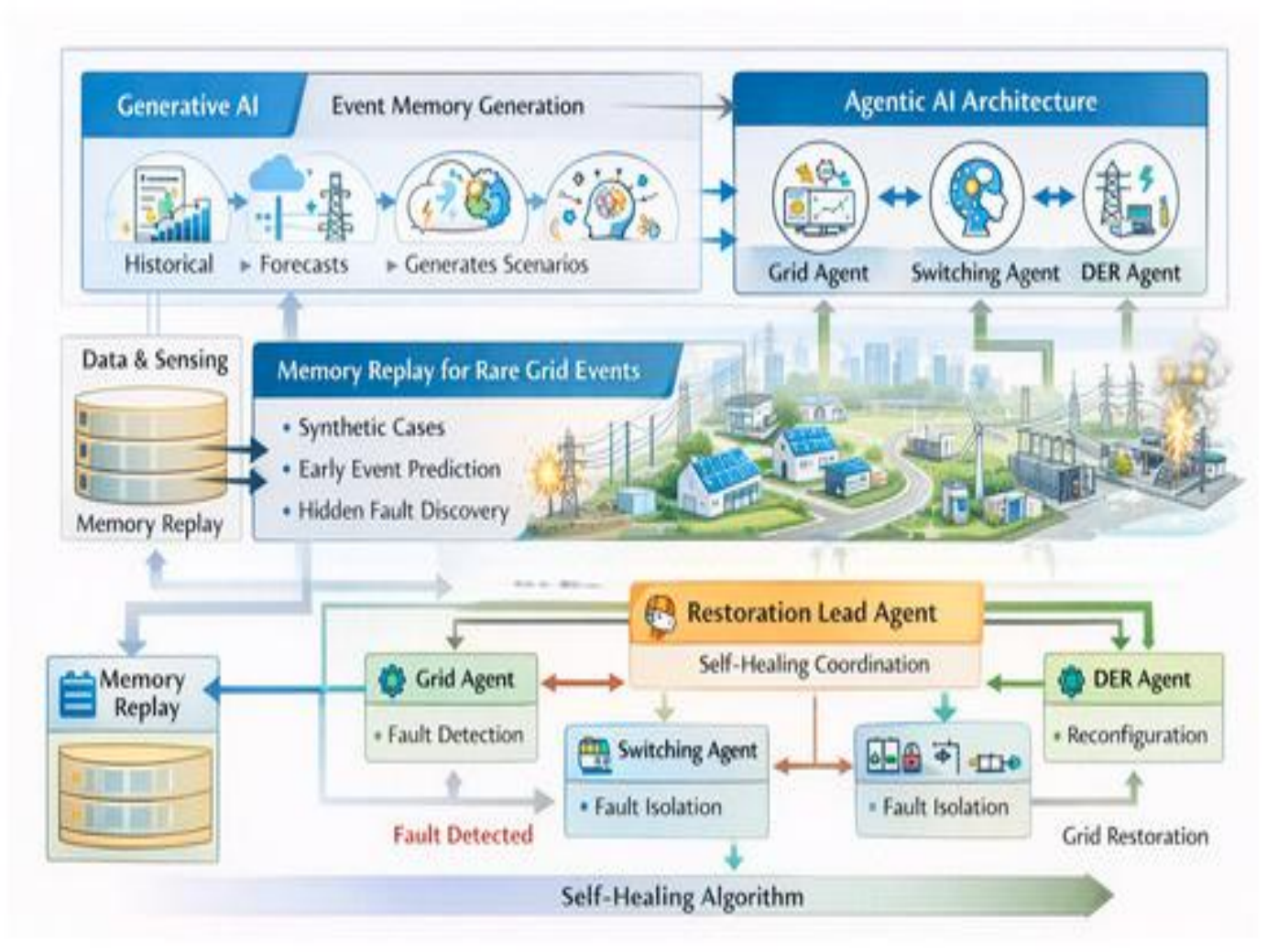
Generative AI and Large Language Models in the Energy Sector

Applications

- Automated report generation and regulatory compliance documentation
- Natural language interfaces for SCADA and energy management systems
- Synthetic data generation for training forecasting and fault models
- Knowledge assistants supporting engineers and operations teams

Considerations

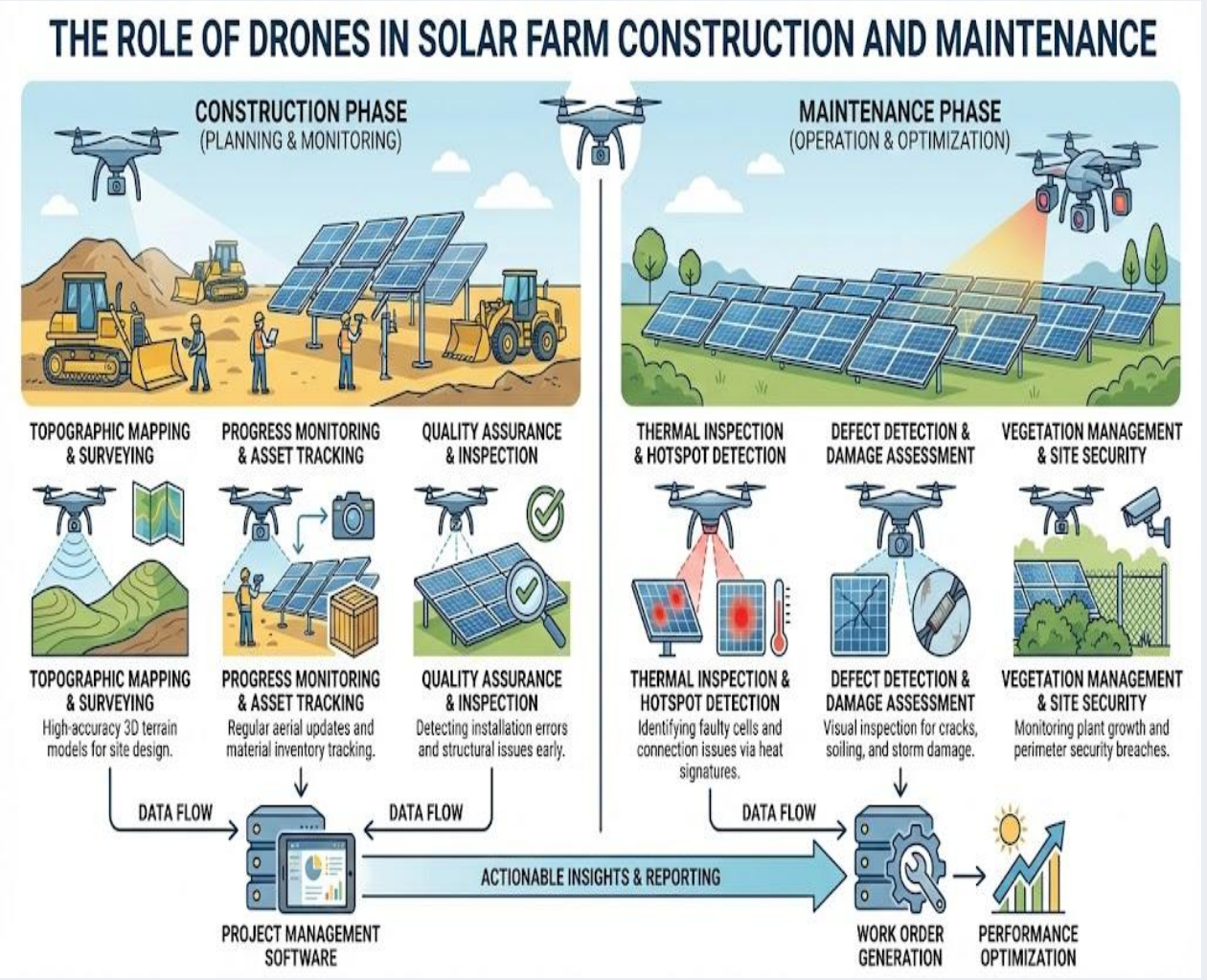
- Outputs require validation against physical and safety constraints
- Data privacy and cybersecurity risks in deployment
- Explainability remains critical for safety-critical decisions
- Integration with existing SCADA and control infrastructure is non-trivial



7. Case Studies

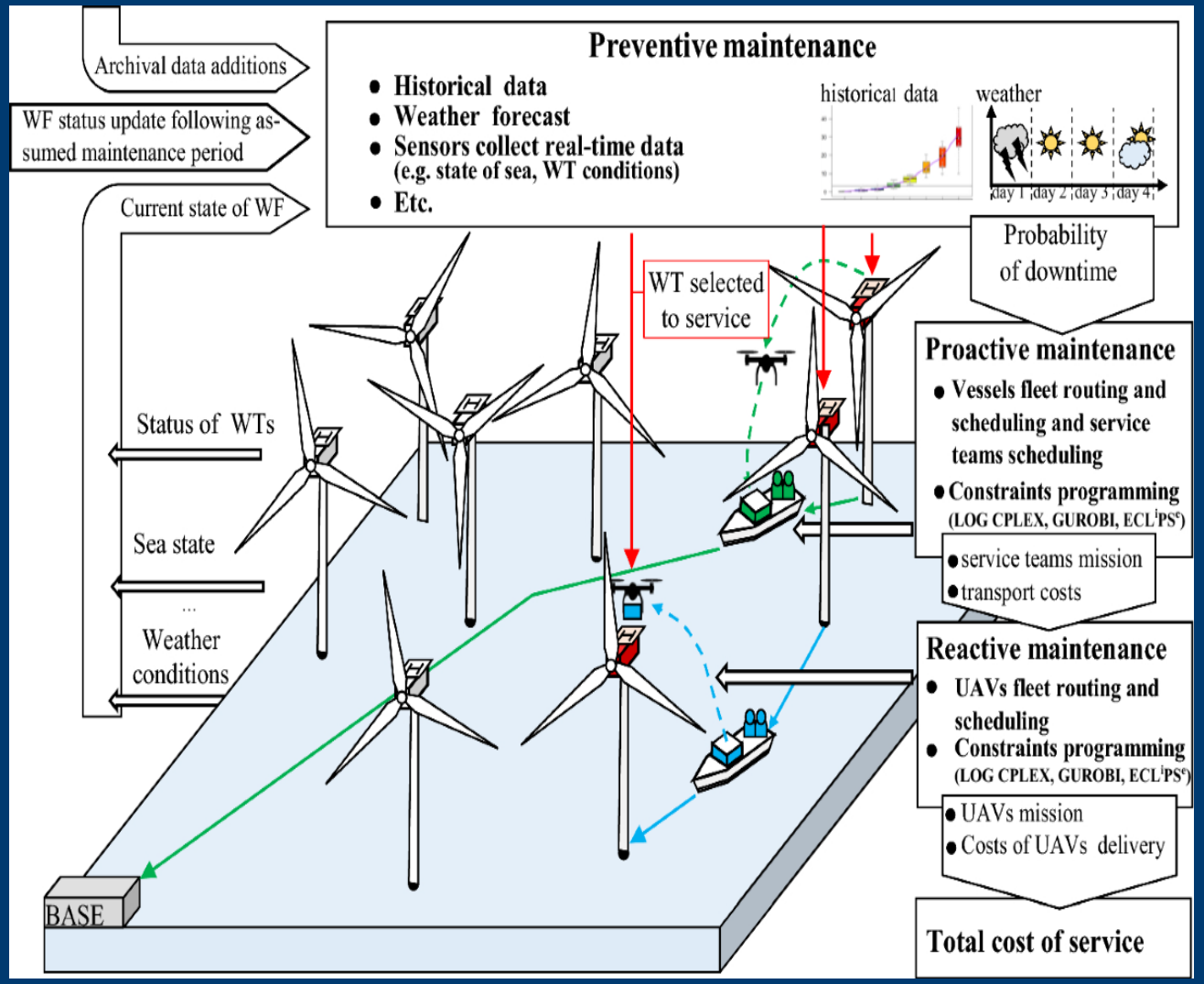
Case Study: AI-Optimized Utility-Scale Solar Farm

- Multi-megawatt solar farm deployed AI-based irradiance forecasting
- Machine learning-driven soiling detection reduced cleaning costs
- Predictive analytics improved inverter fault response time
- Reported measurable gains in annual energy yield and availability
- Demonstrates integration of forecasting, vision, and maintenance AI tools



Case Study: Predictive Maintenance at an Offshore Wind Farm

- Offshore turbines equipped with vibration and SCADA-based monitoring
- Machine learning models flagged early-stage gearbox degradation
- Maintenance scheduled proactively, avoiding costly offshore call-outs
- Reduced unplanned downtime and improved turbine availability
- Highlights AI's value in high-cost, hard-to-access maintenance settings



8. Challenges & Future Outlook

Key Challenges: Data, Interpretability, and Cybersecurity

Technical Challenges

- Data quality, availability, and standardization across sites
- Model generalization across climates and system configurations
- Integration with legacy SCADA and control infrastructure
- Computational and latency requirements for real-time control

Governance & Security Challenges

- Explainability and trust in AI-driven operational decisions
- Cybersecurity risks in connected, AI-enabled systems
- Regulatory and certification frameworks still maturing
- Workforce skills gap in AI and renewable energy integration

Future Trends and Concluding Remarks

- Greater adoption of digital twins and physics-informed AI models
- Increasing use of edge AI for real-time, on-site decision making
- Growing role of generative AI in design, operations, and reporting
- Stronger integration of AI across generation, storage, and grid domains
- AI will be central to reliable, cost-effective renewable energy systems

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52910WA Graduate Certificate in Hydrogen Engineering and Management	6 October 2026
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Professional Certificate of Competency in Power Distribution	3 November 2026
Graduate Certificate in Power System Analysis and Design	4 January 2027
Master of Engineering (Electrical Systems)	4 January 2027
Master of Engineering – Applied Research (Electrical Systems)	4 January 2027
Associate Degree in Electrical Engineering	8 February 2027

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Master of Science (Power System Analysis and Renewable Integration)	5 October 2026
Master of Science (Industrial Automation and Instrumentation Control)	5 October 2026

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Bachelor of Engineering Technology in Electrical Engineering	3 August 2026

Q&A

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