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NEURAL NETWORK-BASED ENERGY STORAGE CONTROL FOR WIND FARMS

~ Using Deep Q Networks

Presented by Group 1

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INTRODUCTION

Energy storage plays a crucial role in modern power systems, especially in renewable energy sources like wind and solar farms. Due to the intermittent nature of renewable generation, efficient energy storage management is necessary to balance supply and demand, optimize energy utilization, and improve grid stability. Traditional control strategies often struggle with the dynamic and uncertain nature of energy production and consumption. This project explores the use of Deep Q-Networks (DQN), a reinforcement learning technique, to develop an adaptive and intelligent approach to energy storage management.

Deep Q Networks

What is DQN

Deep Q-Network (DQN) is an AI algorithm that learns the best actions to take by using past experiences and rewards, helping to optimize decision-making in complex environments like energy storage management.

Why DQN

- Handles Continuous, Uncertain Inputs: Wind speed and power generation are highly unpredictable. DQN can learn an optimal storage policy even in such conditions.
- Optimizes Long-Term Rewards: Unlike simple rule-based methods, DQN learns the best battery charging/discharging strategy by considering future rewards.
- Adapts to Market Prices: If the wind farm is connected to a power grid, DQN can learn to charge batteries when electricity is cheap and sell power when prices are high.

Deep Q Networks

How DQN works

- A neural network is trained to predict the best action in every situation.
- The model is trained using real or simulated energy data.
- Experience Replay: The AI stores past experiences and learns from them.
- Bellman Equation: The AI updates its decision-making to maximize future rewards.
- The trained model continuously monitors energy conditions.
- It chooses the best action (charge, discharge, or hold).
- The system updates the UI dashboard to show battery level & power flow.

LITERATURE REVIEW

Neural Network Based Energy Storage Control For Wind Farms ~ Using Deep Q-Networks

Literature Review

SNo.	Year	Title	Methodology	Key Contributions
1.	2024	Hybrid energy storage system control and capacity allocation considering battery state of charge self-recovery and capacity attenuation in wind farm	It uses a bi-objective model predictive control (MPC) - weighted moving average (WMA) strategy for energy storage target power controlling	A new bi-objective control method considers state of charge and wind power smoothing. A battery life model considering effective capacity attenuation is proposed. Optimized capacity allocation for wind-storage combined system's long-term stability.
2.	2014	Neural Network Based Energy Storage Control for Wind Farms	They have proposed a neural network based ai system to decide how much energy is to be stored or released from the battery.They created a simulink model and simulated a wind farm with 100 wind turbines to see if their AI system reduces power fluctuations.	Instead of traditional methods, they use Neural Networks to dynamically control energy storage. Each wind turbine has its own battery instead of one large storage unit.
3.	2018	Study on Energy Storage System Participating in Frequency Regulation of Wind Farm Based on Polyline Fuzzy Neural Network	They are proposing an energy storage system using polyline fuzzy neural network (PFNN).By taking frequency change, frequency change rate and state of energy storage system as the inputs of PFNN,a frequency control method is proposed.	Uses Polyline Fuzzy Neural Network (PFNN) to manage battery storage in wind farms. Helps stabilize power frequency when wind power fluctuates. By combining batteries with AI control, the system adjusts power output in real-time. The AI-based system reacts quickly to power fluctuations thereby reduces the burden on the main power grid and prevents power blackouts.
4.	2023	Deep Reinforcement Learning for Wind and Energy Storage Coordination in Wholesale Energy and Ancillary Service Markets.	This paper presents a Deep Reinforcement Learning (DRL)-based approach for managing wind energy and battery storage in electricity markets.DRL optimizes how the battery stores and sells energy to maximize revenue and reduce wind curtailment.	Unlike traditional models, this DRL-based system balances storing wind energy with making profits. Unlike old methods that need precise energy price predictions, DRL learns directly from past data.
5.	2019	Energy Storage Management via Deep	The paper follows a learning-based approach to manage energy storage using Deep Q-Networks.The AI model is	Uses Deep Q-Networks (DQN) to manage battery charging/discharging dynamically. Unlike older methods, the system does not assume energy demand or price

PROBLEM STATEMENT

Wind energy is unpredictable, making energy storage management difficult. Traditional methods (rule-based & optimization techniques) struggle with real-time decision-making and uncertainty. Poor energy storage leads to waste, inefficiency, and unstable power supply.

Solution:

- **This project proposes an AI-driven energy storage management system using Deep Q-Networks (DQN). The model will:**

1. **Learn from past energy patterns to make intelligent decisions.**
2. **Dynamically adjust battery charging and discharging based on real-time data.**
3. **Reduce energy waste, increase efficiency, and optimize grid stability.**

OBJECTIVES

1️⃣ Develop a Simulation Environment

Model wind energy generation, battery behavior, and electricity demand.

Create an interactive testbed for training and evaluating the AI model.

2️⃣ Implement Deep Q-Networks for Energy Storage Control

Train a DQN agent to learn optimal battery charging and discharging strategies.

Use reward-based learning to improve decision-making over time.

3️⃣ Compare with Traditional Methods

Evaluate performance against rule-based and optimization-based approaches.

Analyze efficiency, energy savings, and grid stability improvements.

4️⃣ Optimize Model for Real-Time Decision-Making

Improve training efficiency for real-world application.

Ensure the system can adapt quickly to changes in energy demand and supply.

METHODOLOGY

Neural Network Based Energy Storage Control For Wind Farms
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Methodology

1. Problem Understanding & Data Collection:
- Identify key factors affecting energy storage (wind energy output, battery level, power demand).
- Collect wind energy data and electricity demand patterns.
- Define the actions the AI can take (Charge, Discharge, Hold).

2.Implement Deep Q-Networks (DQN):
- Train an AI agent using Reinforcement Learning (RL). The AI will:

i. Observe battery level, energy input, and demand.
ii. Decide whether to charge, discharge, or hold energy.
iii. Receive rewards for good actions (e.g., storing energy efficiently).
iv. Learn from mistakes and improve over time.

3. Build a Simulation Environment:
- Create a virtual energy system to simulate:

i. Wind energy production
ii. Battery charging & discharging
iii. Power demand changes over time.

4. Train & Optimize the Model:
- Run multiple simulations to train the AI.
- Use a reward system to guide learning:

i. Reward for efficient energy use.
ii. Penalty for energy waste or overcharging.

CHALLENGES

1️⃣ Data Availability & Quality

The AI model needs a lot of real-time data (wind energy, power demand, battery levels).

If the data is incomplete or inaccurate, the model may make bad decisions.

2️⃣ Training Time & Computational Cost

Training a Deep Q-Network (DQN) takes a lot of time and processing power.

If not trained well, the model might not learn the best energy management strategies.

3️⃣ Handling Uncertainty

Wind energy and electricity demand change unpredictably.

The model must be flexible to handle sudden weather changes.

4️⃣ Battery Efficiency & Degradation

Frequent charging/discharging can damage batteries over time.

The model should optimize for both efficiency and long-term battery health.

5️⃣ Real-World Implementation

Testing the model in real wind farms and grids is complex and expensive.

It needs to be integrated with existing power systems without disruptions.

HOW UID USED

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How is UID used ?

Key Elements of the User Interface:

- Battery Level Display: Shows the current charge percentage.
- Wind Energy Production: Displays how much energy is being generated.
- Power Demand Indicator: Shows how much energy is currently needed.
- Control Buttons:

Charge: Increases battery level.
Discharge: Decreases battery level.
Reset: Resets battery to 50%.

How Users Interact with the UI ?

1. The user opens the dashboard.
2. Reads current battery level, wind energy, and power demand.
3. Press a button to charge, discharge, or reset the battery.
4. The interface updates instantly to reflect changes.

- Our UI provides a simple and interactive way to manage energy storage.
- Users can monitor battery levels, wind power, and demand.
- Real-time controls allow efficient energy management.
- Future improvements will make it more advanced and intelligent.

FUTURE SCOPE

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Future Scope

1. Real-World Deployment & Smart Grid Integration:
Connect the AI model with actual wind farms & power grids. Work with smart meters & IoT devices for real-time energy tracking.

2. Advanced AI Models:
Use Deep Reinforcement Learning (DQN) to predict energy demand better. Improve the model to handle uncertainty & extreme weather conditions.

3. Multi-Agent Energy Management:
Instead of one AI model, multiple models can work together. Example: One AI handles wind energy, another manages battery storage, and another predicts demand.

4. Integration with Other Renewable Sources:
Extend the system to manage solar, hydro, and other renewable energy along with wind energy.

5. Cost Optimization & Market-Based Energy Trading:
The AI can learn to sell excess energy when market prices are high.Helps reduce energy waste and maximize revenue for power companies.

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THANK YOU