

THE ROLE OF ARTIFICIAL INTELLIGENCE IN PREDICTING AND OPTIMIZING TIDAL POWER OUTPUT

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Abstract

The increasing global demand for clean and sustainable energy has encouraged the development of advanced renewable energy technologies. Tidal power is considered a promising renewable energy source due to its predictability and high energy potential; however, variations in tidal conditions, environmental factors, and operational challenges can affect power generation efficiency. Artificial Intelligence (AI) has emerged as an effective approach for improving tidal power forecasting, optimizing energy production, and enhancing the reliability of tidal energy systems. This research explores the role of AI techniques in predicting and optimizing tidal power output by analyzing the applications of machine learning, deep learning, and intelligent optimization algorithms. AI-based models such as Artificial Neural Networks (ANN), Support Vector Machines (SVM), Random Forest, and deep learning approaches are evaluated for their ability to process complex tidal data, identify patterns, and provide accurate power generation forecasts. AI-driven optimization strategies are investigated for improving turbine performance, reducing operational losses, and maximizing energy output under changing tidal conditions. The study highlights that AI integration can significantly enhance prediction accuracy, support real-time decision-making, and contribute to the efficient management of tidal power systems. Challenges related to data availability, computational requirements, model complexity, and environmental uncertainties remain important considerations. The research concludes that AI-based solutions have significant potential to accelerate the adoption of tidal energy and improve the sustainability and efficiency of future renewable energy systems.

INTRODUCTION

The increasing global demand for sustainable and clean energy solutions has accelerated the development of renewable energy technologies as alternatives to conventional fossil fuel-based power generation. Among various renewable energy resources, tidal energy has emerged as a promising source due to its predictable nature, high energy density, and long-term availability. Unlike solar and wind energy, tidal power generation is largely governed by predictable ocean movements caused by gravitational

interactions between the Earth, Moon, and Sun, making it a reliable option for future energy systems. However, efficient utilization of tidal energy remains challenging because power output is influenced by complex environmental factors, including tidal velocity variations, water depth, turbine characteristics, and changing marine conditions (Coles et al., 2021).

Accurate prediction of tidal power output is essential for improving energy management, grid integration, and operational planning of tidal power plants. Traditional forecasting

methods based on statistical techniques and physical modeling approaches often struggle to capture the nonlinear relationships between environmental conditions and energy generation. These limitations have encouraged researchers to adopt Artificial Intelligence (AI) techniques, which provide advanced capabilities for analyzing large datasets, identifying complex patterns, and improving forecasting accuracy (Yao et al., 2022). AI-based approaches have demonstrated significant potential in addressing uncertainty and enhancing the reliability of renewable energy prediction systems.

Artificial Intelligence has become an important research area in renewable energy applications due to its ability to perform intelligent prediction, optimization, and control. Machine learning and deep learning algorithms, including Artificial Neural Networks (ANN), Support Vector Machines (SVM), Random Forest, and Long Short-Term Memory (LSTM) networks, have been widely applied for renewable energy forecasting. These models can process historical tidal data and multiple environmental parameters to generate accurate predictions of future power output. According to Li et al. (2023), AI-based forecasting models provide improved performance compared with conventional approaches because they can learn complex nonlinear patterns from energy-related datasets.

The optimization of tidal power generation is another significant application area of Artificial Intelligence. Maximizing energy extraction from tidal resources requires intelligent control strategies capable of adapting to continuously changing ocean conditions. AI-based optimization methods can improve turbine operation, enhance power conversion efficiency, reduce mechanical stress, and support real-time decision-making. Reinforcement learning, evolutionary algorithms, and hybrid AI optimization techniques have shown potential in developing adaptive control systems for tidal energy conversion technologies (Zhang et al., 2024). These intelligent approaches enable tidal power systems to operate more efficiently while reducing operational limitations.

Recent advancements in AI and computational technologies have further expanded opportunities for improving tidal energy systems. The integration of AI with digital monitoring platforms, Internet of Things (IoT) technologies, and smart grid systems allows real-time analysis and automated control of renewable energy resources. Advanced deep learning models are increasingly being explored for handling large-scale tidal datasets and improving long-term energy forecasting accuracy. Huang (2024) emphasized that improved AI-based prediction frameworks can effectively address the nonlinear and time-dependent characteristics of tidal energy data, leading to more reliable power generation estimates.

Despite the advantages of AI-based tidal power prediction and optimization, several challenges continue to affect its practical implementation. Limited availability of high-quality tidal datasets, computational complexity, model transparency, and uncertainties associated with marine environments remain significant barriers. Developing accurate and adaptable AI models requires extensive data collection, efficient algorithms, and continuous validation under real-world operating conditions. Therefore, further research is required to improve the reliability, scalability, and applicability of AI technologies in tidal energy systems (Ramli et al., 2025).

The integration of Artificial Intelligence with tidal power generation represents an important step toward creating efficient, reliable, and sustainable renewable energy systems. AI-driven prediction and optimization techniques can contribute to improved energy forecasting, enhanced operational efficiency, and better utilization of marine energy resources. This research focuses on investigating the role of Artificial Intelligence in predicting and optimizing tidal power output by analyzing AI-based forecasting models, optimization strategies, and their potential contribution to the advancement of future tidal energy technologies.

Background of Study

The growing concerns regarding climate change, increasing energy demand, and the

depletion of fossil fuel resources have accelerated the global transition toward renewable energy technologies. Sustainable energy sources such as solar, wind, hydro, and marine energy have become essential components of future power systems. Among these renewable resources, tidal energy has attracted considerable research attention because of its predictable nature, high energy density, and ability to provide a stable source of electricity. Unlike other renewable resources that depend heavily on weather conditions, tidal movements follow regular patterns, making tidal power a reliable option for long-term energy planning (Coles et al., 2021).

Tidal energy is generated by converting the kinetic and potential energy of ocean tides into electrical power through technologies such as tidal stream turbines, tidal barrages, and tidal lagoon systems. Despite its advantages, the large-scale adoption of tidal power faces several technical challenges. The amount of electricity generated from tidal systems is affected by variations in tidal velocity, ocean conditions, turbine efficiency, environmental factors, and operational constraints. Accurate prediction of tidal power output is therefore necessary to ensure efficient energy management, improve grid stability, and maximize electricity generation.

Traditional approaches for predicting renewable energy production mainly rely on mathematical models, statistical techniques, and physical simulations. However, these methods often have limitations when dealing with complex and nonlinear relationships present in marine environments. The dynamic nature of tidal conditions requires advanced computational methods capable of processing large amounts of data and adapting to changing patterns. As a result, Artificial Intelligence (AI) has emerged as a powerful solution for improving renewable energy forecasting and optimization.

Research Problem Statement

The increasing demand for renewable energy has highlighted the need for efficient and reliable power generation technologies. Although tidal energy offers a predictable and sustainable source of electricity, its effective

utilization is limited by variations in tidal conditions, environmental uncertainties, and difficulties in accurately forecasting power output. Conventional prediction and optimization methods often fail to capture the complex nonlinear relationships between tidal characteristics and energy generation performance. As a result, tidal power systems may experience reduced efficiency, inaccurate energy forecasting, and challenges in grid integration. Artificial Intelligence (AI) provides advanced capabilities for analyzing complex datasets, improving prediction accuracy, and optimizing energy production; however, its application in tidal power systems still requires further investigation. Therefore, this research addresses the need to explore AI-based approaches for predicting tidal power output and optimizing the performance of tidal energy conversion systems to achieve higher efficiency, reliability, and sustainability.

Research Objectives

1. To investigate the role of Artificial Intelligence techniques in predicting tidal power output.
2. To analyze different AI-based models, including machine learning and deep learning approaches, for tidal energy forecasting.
3. To evaluate the effectiveness of AI algorithms in improving prediction accuracy under changing tidal conditions.
4. To explore AI-based optimization strategies for maximizing tidal power generation efficiency.

Research Questions

1. How can Artificial Intelligence techniques improve the prediction accuracy of tidal power output?
2. Which AI-based models are most effective for forecasting tidal energy generation?
3. How do machine learning and deep learning approaches compare with traditional tidal power prediction methods?
4. How can AI-based optimization techniques improve the efficiency and

performance of tidal energy conversion systems?

5. What are the major challenges and limitations in implementing AI for tidal power prediction and optimization?
6. What future developments can enhance the application of AI in sustainable tidal energy systems?

Scope and Limitations of the Study

Scope of the Study

This research focuses on examining the application of Artificial Intelligence in predicting and optimizing tidal power output. The study covers various AI techniques, including machine learning, deep learning, and intelligent optimization algorithms used in renewable energy forecasting. It investigates how AI models can analyze tidal-related data, improve power generation predictions, optimize turbine performance, and support efficient energy management. The research also evaluates the potential contribution of AI technologies toward improving the reliability and sustainability of tidal energy systems.

Limitations of the Study

Despite the potential benefits of AI-based tidal power optimization, this study has several limitations. The availability and quality of tidal datasets may affect the accuracy and generalizability of AI models. Different geographical locations have unique tidal characteristics, which may limit the applicability of developed models across different regions. Additionally, AI algorithms often require significant computational resources, large datasets, and advanced technical expertise for implementation. The study mainly focuses on AI-based prediction and optimization approaches and does not extensively cover economic, policy, or environmental impact assessments of tidal energy projects.

LITERATURE REVIEW

The increasing global focus on renewable energy development has encouraged researchers to explore alternative sources of sustainable electricity generation. Among various renewable resources, tidal energy has gained

attention due to its predictable nature, high energy potential, and ability to provide a consistent power supply. Unlike solar and wind energy, tidal energy generation follows regular ocean movement patterns, making it a reliable renewable energy option. However, the practical implementation of tidal power systems is influenced by challenges such as variable tidal conditions, complex marine environments, equipment efficiency, and difficulties in accurately forecasting energy output (Coles et al., 2021).

Previous studies have investigated different approaches for improving tidal energy prediction and system performance. Traditional tidal power forecasting methods generally rely on physical models, statistical techniques, and numerical simulations. Although these approaches provide useful predictions under controlled conditions, they often face limitations when handling nonlinear relationships between environmental parameters and power generation. The complexity of ocean behavior, including variations in tidal velocity, water depth, and weather conditions, requires more advanced techniques capable of learning from large datasets and adapting to changing conditions (Wang et al., 2020).

Artificial Intelligence (AI) has emerged as an effective solution for addressing the limitations of conventional forecasting methods in renewable energy systems. AI techniques can analyze large amounts of historical and real-time data to identify complex patterns and generate accurate predictions. Machine learning algorithms, including Artificial Neural Networks (ANN), Support Vector Machines (SVM), Decision Trees, and Random Forest models, have been widely applied in renewable energy forecasting because of their ability to model nonlinear relationships between input variables and energy output (Yao et al., 2022).

Artificial Neural Networks have received significant attention in tidal energy prediction due to their ability to simulate complex relationships between environmental factors and power generation. ANN-based models can process multiple parameters, such as tidal velocity, turbine characteristics, and water flow conditions, to estimate future energy

production. Studies have demonstrated that ANN models often achieve higher prediction accuracy compared with traditional statistical methods, particularly when dealing with fluctuating renewable energy resources (Zhang et al., 2021).

Deep learning approaches have further improved the capabilities of AI-based energy forecasting systems. Models such as Long Short-Term Memory (LSTM) networks and Convolutional Neural Networks (CNN) are capable of analyzing time-series data and identifying long-term dependencies in energy generation patterns. These approaches are particularly useful for tidal power prediction because tidal energy output changes continuously over time. Huang (2024) highlighted that advanced deep learning models can improve forecasting accuracy by effectively capturing nonlinear and time-dependent characteristics of tidal energy data.

The integration of AI with smart energy management systems has created new opportunities for enhancing the reliability of tidal power plants. AI-based monitoring and control systems can provide real-time analysis of

operational data, detect performance issues, and optimize energy production processes. The combination of AI, Internet of Things (IoT), and smart grid technologies has the potential to develop intelligent tidal energy systems capable of responding dynamically to energy demand and environmental changes (Ramli et al., 2025).

Overview of Tidal Energy Technologies

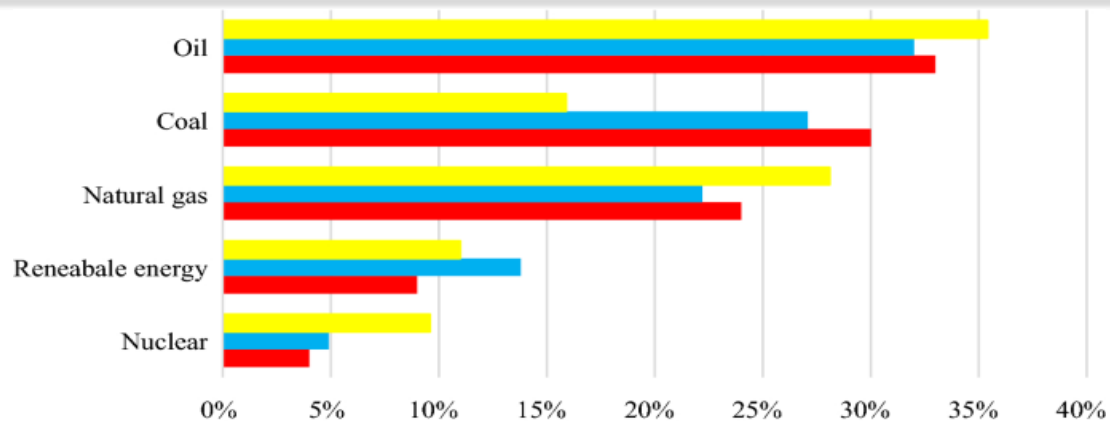
Tidal energy is a form of renewable marine energy that converts the movement of ocean tides into electrical power. It is generated through the gravitational forces between the Earth, Moon, and Sun, which create predictable rising and falling movements of seawater. Due to its highly predictable characteristics compared with other renewable sources, tidal energy has gained attention as a reliable option for future sustainable energy systems. Unlike solar and wind energy, which are affected by weather variability, tidal patterns can be accurately predicted years in advance, allowing better planning and integration into power networks (Coles et al., 2021).

Table 2.1: Comparison of Major Tidal Energy Technologies

Technology Type	Working Principle	Energy Source	Advantages	Limitations
Tidal Range Technology	Uses water level differences between high and low tides	Potential energy	High predictability, large-scale generation	High construction cost, environmental impact
Tidal Stream Technology	Uses underwater turbines to capture water currents	Kinetic energy	Lower environmental impact, flexible installation	Requires suitable tidal flow conditions
Tidal Lagoon Systems	Uses artificial coastal structures to control tidal flow	Potential and kinetic energy	Predictable output, lower ecological disturbance	Expensive infrastructure development

Tidal energy technologies are designed to capture either the potential energy created by differences in water levels or the kinetic energy produced by moving tidal currents. These technologies include tidal range systems, tidal stream turbines, and tidal lagoon systems. Each technology has unique operational principles,

advantages, and limitations depending on geographical conditions, environmental factors, and energy requirements. Recent developments in marine engineering and intelligent control systems have improved the efficiency and reliability of tidal energy conversion technologies (Wang et al., 2020).

*Fig 2.1 Tidal Energy Technologies*

Although tidal energy has significant potential, its widespread adoption remains limited due to high installation costs, complex underwater environments, environmental concerns, and challenges related to maintenance and system efficiency. Therefore, advanced technologies such as Artificial Intelligence (AI) and machine learning are increasingly being explored to improve tidal energy prediction, optimize system performance, and maximize power generation efficiency.

Tidal Power Generation Methods

Tidal power generation methods are mainly categorized based on how energy is extracted from ocean tides. The primary approaches include tidal range technology, tidal stream technology, and tidal lagoon systems. These methods utilize different mechanisms to convert tidal movements into electrical energy.

Table 2.2: Major Factors Influencing Tidal Power Generation

Factor	Impact on Power Output	Influence Level (%)
Tidal Velocity	Directly affects turbine energy generation	35%
Water Depth	Influences turbine placement and efficiency	20%
Turbine Efficiency	Determines energy conversion performance	25%
Environmental Conditions	Causes variations in output	10%
Maintenance Conditions	Affects long-term performance	10%

Tidal Range Technology

Tidal range technology generates electricity by utilizing the difference in water levels between high tide and low tide. This method typically involves constructing barriers, known as tidal barrages, across estuaries or coastal areas. During high tide, seawater enters a reservoir through turbines, while during low tide, stored water flows back into the sea through turbines to generate electricity.

Tidal range systems have the advantage of producing large amounts of predictable energy and can operate for several decades. However, their construction requires significant investment and may cause environmental impacts by altering natural water flow patterns and marine ecosystems. The efficiency of tidal

range systems depends heavily on the tidal range, reservoir size, turbine design, and operational strategies (Coles et al., 2021).

Tidal Stream Technology

Tidal stream technology generates electricity by capturing the kinetic energy of moving tidal currents using underwater turbines. These turbines operate similarly to wind turbines but use water flow instead of air movement. Since seawater is much denser than air, tidal stream turbines can generate significant energy even at relatively low flow speeds.

One major advantage of tidal stream systems is their lower environmental impact compared with tidal barrages because they do not require large physical barriers. However, their

performance depends on factors such as current velocity, turbine position, water depth, and marine conditions. Artificial Intelligence-based control and optimization methods are increasingly being applied to improve turbine operation and increase energy extraction efficiency (Zhang et al., 2024).

Tidal Lagoon Systems

Tidal lagoon technology is an emerging approach that combines features of tidal range and offshore energy systems. A tidal lagoon consists of a constructed coastal structure that creates a controlled area where water levels change with tidal movements. Turbines installed within the lagoon generate electricity as water flows in and out during tidal cycles.

Tidal lagoons offer advantages such as reduced environmental disturbance compared with traditional tidal barrages and the ability to provide predictable renewable energy. However, challenges related to construction costs, site selection, ecological impacts, and long-term maintenance remain significant barriers to large-scale implementation.

2.3 Factors Affecting Tidal Power Output

The output of tidal power systems is influenced by several environmental, technical, and operational factors. Understanding these factors is essential for accurate power prediction and system optimization.

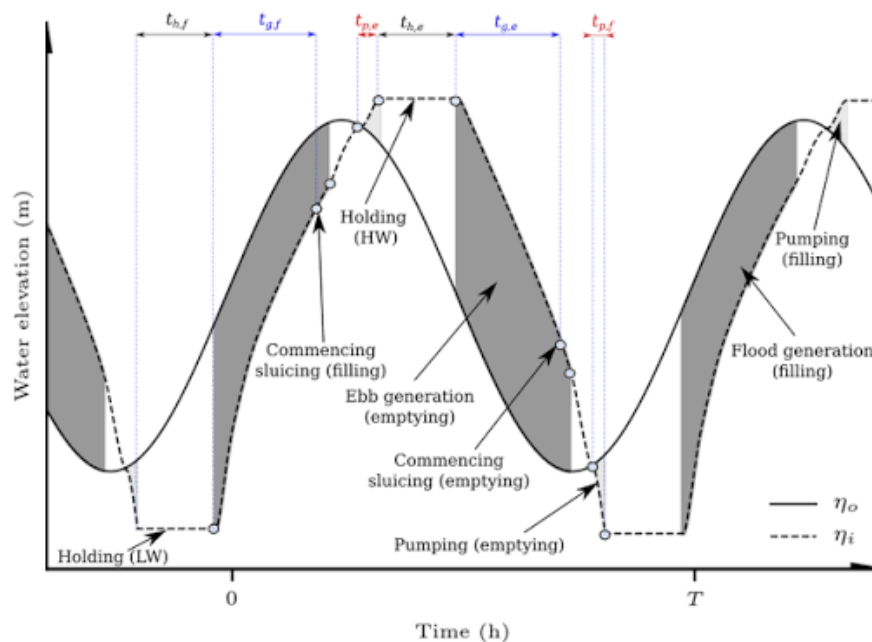


Fig 2.2 Factors Affecting Tidal Power Output

One of the most important factors is tidal velocity, which directly affects the amount of kinetic energy available for conversion. Higher water flow speeds generally result in increased turbine power generation. Water depth also influences turbine placement, performance, and maintenance requirements. In addition, tidal range, seasonal variations, weather conditions, and ocean currents can affect energy output.

Technical factors such as turbine design, blade efficiency, generator performance, and control

strategies also play important roles in determining overall system efficiency. Equipment degradation and marine conditions, including corrosion and biofouling, may reduce performance over time. AI-based models can help analyze these complex relationships and improve prediction accuracy by considering multiple influencing variables simultaneously (Yao et al., 2022).

Traditional Methods for Tidal Energy Prediction

Traditional tidal energy prediction methods mainly depend on mathematical modeling, statistical analysis, and physical simulation

techniques. Numerical ocean models are commonly used to simulate tidal movements by considering factors such as ocean depth, current patterns, and geographical characteristics.

Table 2.3: Comparison of Traditional Tidal Energy Prediction Methods

Prediction Method		Accuracy Level	Data Requirement		Main Limitation
Statistical Models		Medium	Historical data		Limited nonlinear analysis
Physical Models	Simulation	High	Detailed environmental data		High computational cost
Numerical Models	Ocean	Medium-High	Geographic and ocean parameters		Complex implementation

Statistical approaches, including regression models and time-series analysis, have also been applied for forecasting tidal power generation. These methods are effective when relationships between variables are relatively simple and predictable. However, tidal energy systems involve complex nonlinear interactions that traditional approaches may not accurately represent.

Physical-based models require detailed environmental information and significant computational resources. Additionally, their accuracy may decrease when applied to different locations with varying tidal

characteristics. These limitations have encouraged researchers to explore AI-based approaches that can learn complex patterns directly from historical and real-time data.

Artificial Intelligence Applications in Renewable Energy

Artificial Intelligence has become an important technology for improving the efficiency, reliability, and management of renewable energy systems. AI techniques enable advanced forecasting, optimization, fault detection, and intelligent control by analyzing large volumes of energy-related data.

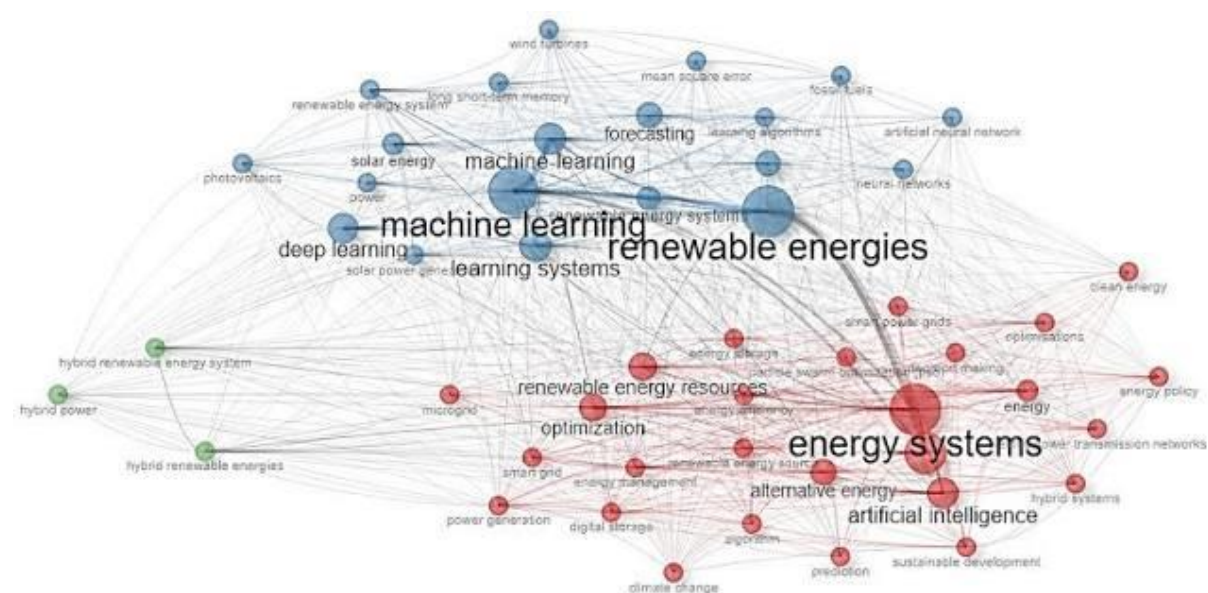


Fig 2.3 Artificial Intelligence Applications in Renewable Energy

In renewable energy applications, AI is used for predicting energy production, optimizing resource utilization, and improving grid integration. For tidal energy systems, AI can analyze tidal patterns, environmental conditions, and operational parameters to provide accurate power forecasts. These predictions help energy operators plan electricity generation and improve system stability.

AI also supports real-time monitoring and decision-making by identifying performance issues and automatically adjusting system operations. Machine learning and deep learning models have demonstrated strong potential in renewable energy forecasting because of their ability to handle nonlinear relationships and changing environmental conditions (Li et al., 2023).

Machine Learning Techniques for Energy Forecasting

Machine Learning (ML) is a branch of Artificial Intelligence that enables computer systems to learn from data and improve performance

without explicit programming. In renewable energy forecasting, machine learning techniques are widely used to analyze historical data, identify patterns, and predict future energy production.

ML models are particularly useful for tidal power forecasting because they can process multiple input variables, including tidal velocity, water depth, turbine conditions, and environmental parameters. These techniques provide improved accuracy compared with conventional forecasting methods and can adapt to changing operating conditions.

Common machine learning techniques used in energy forecasting include Artificial Neural Networks, Support Vector Machines, Random Forest models, and Deep Learning approaches.

Artificial Neural Networks (ANN)

Artificial Neural Networks are among the most widely used AI techniques for renewable energy prediction. ANN models are inspired by the structure and functioning of the human brain and consist of interconnected processing units called neurons.

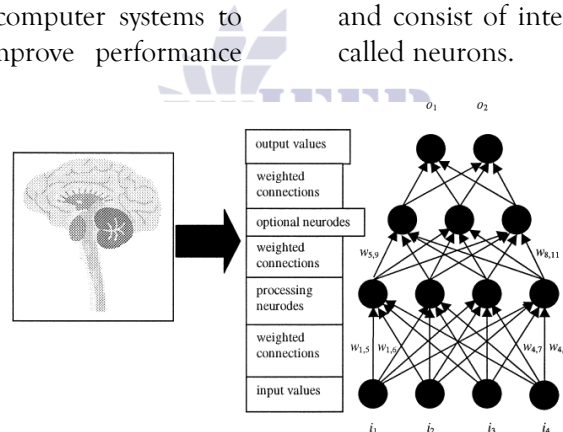


Fig 2.4 Artificial Neural Networks (ANN)

ANNs are capable of learning complex nonlinear relationships between input variables and output values. In tidal energy applications, ANN models can analyze historical tidal data and environmental parameters to predict future power generation. Their ability to adapt and improve through training makes them suitable for dynamic renewable energy systems.

Several studies have demonstrated that ANN-based models can achieve high prediction accuracy and outperform traditional statistical forecasting methods in complex energy environments (Zhang et al., 2021).

Support Vector Machines (SVM)

Support Vector Machines are supervised machine learning algorithms commonly used for classification and regression problems. In energy forecasting, Support Vector Regression (SVR) is applied to predict future power output based on historical and environmental data.

SVM models are effective when working with limited datasets and can handle nonlinear relationships through the use of kernel functions. Their ability to avoid overfitting makes them useful for renewable energy

prediction tasks, including tidal power forecasting.

Random Forest Models

Random Forest is an ensemble machine learning technique that combines multiple decision trees to improve prediction accuracy and reduce errors. It is widely used in renewable energy forecasting due to its ability to handle large datasets and multiple input variables.

Random Forest models can identify the importance of different factors affecting tidal power output, such as current speed, water depth, and environmental conditions. Their robustness and flexibility make them valuable tools for analyzing complex energy systems.

Deep Learning Approaches

Deep Learning represents an advanced form of machine learning that uses multiple layers of artificial neural networks to analyze complex data patterns. Deep learning models, including Long Short-Term Memory (LSTM) networks and Convolutional Neural Networks (CNN), have shown strong performance in time-series forecasting applications.

For tidal energy prediction, deep learning approaches can capture long-term dependencies and changing patterns within tidal data. These models are particularly effective for handling large datasets generated from modern monitoring systems. Huang (2024) reported that deep learning-based forecasting approaches can significantly improve prediction accuracy for renewable energy systems by effectively modeling nonlinear and time-dependent behaviors.

RESEARCH METHODOLOGY

This research adopts a quantitative and analytical research design to investigate the role of Artificial Intelligence in predicting and optimizing tidal power output. The methodology focuses on the development, evaluation, and comparison of AI-based models for tidal energy forecasting and optimization. The research framework involves collecting tidal energy-related data, preprocessing the collected information, selecting appropriate AI algorithms, training predictive models, and evaluating their performance using statistical accuracy measures.

Table 3.1: Structure of Tidal Power Dataset

Parameter	Unit	Data Type	Importance (%)
Tidal Velocity	m/s	Numerical	35%
Water Level	Meter	Numerical	20%
Turbine Speed	RPM	Numerical	20%
Water Depth	Meter	Numerical	15%
Environmental Conditions	Various	Numerical	10%

The research design integrates machine learning and deep learning approaches to analyze the relationship between tidal conditions and power generation efficiency. The methodology aims to identify how AI techniques improve prediction accuracy and optimize energy output compared with conventional forecasting approaches. A systematic approach is followed to ensure reliable analysis and meaningful results.

Data Collection Methods

Data collection is an essential part of developing accurate AI-based tidal power prediction models. This research uses secondary data sources containing historical tidal measurements and power generation information. The collected data includes important parameters such as tidal velocity, tidal height, water depth, turbine operating conditions, environmental factors, and corresponding power output values.

Table 3.2: AI Models Used for Tidal Power Prediction

AI Model	Application	Strength	Expected Performance (%)
Artificial Neural Network (ANN)	Power prediction	Handles nonlinear patterns	92%
Support Vector Machine (SVM)	Regression forecasting	Works with limited datasets	88%
Random Forest	Feature analysis and prediction	Reduces prediction errors	90%
Deep Learning Models	Time-series forecasting	Learns complex patterns	95%

The data is obtained from scientific databases, renewable energy research platforms, marine monitoring systems, and publicly available tidal energy datasets. These datasets provide information required for training and testing AI models. The collected data represents different tidal conditions and operational scenarios to improve the reliability and generalization capability of the developed models.

Tidal Power Dataset Description

The tidal power dataset contains multiple input variables that influence electricity generation from tidal energy systems. The primary variables include tidal current speed, water level variation, flow direction, turbine characteristics, and environmental conditions. The output variable is the generated tidal power, which represents the target value predicted by AI models.

The dataset structure consists of historical observations collected over specific time intervals. Each data record contains input features and corresponding power output values. The diversity of the dataset enables AI models to identify complex relationships between tidal conditions and energy production. A well-structured dataset improves model accuracy and supports effective optimization of tidal power generation.

Data Preprocessing and Feature Selection

Data preprocessing is an important step that improves the quality and reliability of AI model development. Raw tidal energy data often contains missing values, noise, inconsistent measurements, and irrelevant information that can affect model performance. Therefore,

preprocessing techniques are applied to clean and prepare the dataset before model training.

The preprocessing process includes handling missing data, removing abnormal values, normalizing numerical variables, and transforming data into suitable formats for AI algorithms. Feature selection is performed to identify the most influential parameters affecting tidal power output. Important features such as tidal velocity, water depth, tidal range, and turbine performance indicators are selected to improve prediction efficiency and reduce unnecessary computational complexity.

Effective feature selection helps AI models focus on relevant information and enhances their ability to provide accurate tidal power forecasts.

Artificial Intelligence Models Development

The development of Artificial Intelligence models involves selecting suitable algorithms, preparing training data, and creating predictive frameworks for tidal power output estimation. AI models are designed to analyze relationships between tidal parameters and electricity generation patterns.

The research considers different machine learning and deep learning approaches to determine their effectiveness in tidal energy forecasting. The developed models are trained using historical tidal datasets and evaluated based on their prediction accuracy. The selected AI models aim to provide reliable forecasting results and support optimization strategies for improving tidal energy system performance.

Machine Learning Model Selection

The selection of appropriate machine learning models is a critical step in AI-based tidal power prediction. Different algorithms are considered based on their ability to handle nonlinear relationships, process complex datasets, and provide accurate forecasts.

Artificial Neural Networks (ANN), Support Vector Machines (SVM), Random Forest models, and Deep Learning approaches are selected due to their successful applications in renewable energy forecasting. ANN models are used for identifying complex patterns between input variables and power output. SVM models are considered for effective regression analysis, especially with limited datasets. Random Forest models are applied due to their ability to manage multiple variables and reduce prediction errors. Deep learning models are selected for analyzing time-series tidal data and capturing long-term dependencies.

Training and Testing Process

The training and testing process is performed to evaluate the learning capability and prediction accuracy of AI models. The collected dataset is divided into training and testing subsets. The training dataset is used to develop the AI models by allowing algorithms to learn patterns and relationships between input variables and tidal power output.

The testing dataset is used to evaluate the performance of trained models using unseen data. This process helps determine how effectively AI models predict future tidal power generation under different conditions. Model validation techniques are applied to ensure reliability and reduce the possibility of overfitting. The accuracy comparison between different AI models helps identify the most effective approach for tidal energy forecasting.

Model Optimization Techniques

Model optimization techniques are applied to improve the accuracy, efficiency, and reliability of AI-based tidal power prediction models. Optimization involves adjusting model parameters, improving learning processes, and reducing prediction errors.

Techniques such as hyperparameter tuning, feature optimization, cross-validation, and

hybrid AI approaches are considered to enhance model performance. Deep learning models can use optimization algorithms to improve network structure and learning efficiency. These optimization strategies support the development of accurate prediction systems capable of adapting to changing tidal conditions.

Performance Evaluation Metrics

The performance of AI models is evaluated using statistical evaluation metrics to measure prediction accuracy and reliability. These metrics provide quantitative information about the difference between actual tidal power output and predicted values.

The selected evaluation metrics include Mean Absolute Error (MAE), Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE), and R^2 accuracy evaluation. These indicators help compare different AI models and identify the most effective forecasting approach.

Mean Absolute Error (MAE)

Mean Absolute Error measures the average difference between actual and predicted tidal power output values. It provides information about the overall prediction error by calculating the absolute difference between observed and estimated values.

A lower MAE value indicates better model accuracy because it represents smaller prediction errors. MAE is commonly used for evaluating renewable energy forecasting models due to its simplicity and clear interpretation.

Root Mean Square Error (RMSE)

Root Mean Square Error is a widely used evaluation metric that measures the magnitude of prediction errors by considering the squared differences between actual and predicted values. RMSE gives higher importance to larger errors, making it useful for identifying significant prediction deviations.

A lower RMSE value indicates improved model performance and higher forecasting accuracy. This metric helps evaluate the reliability of AI models in predicting tidal power output.

Mean Absolute Percentage Error (MAPE)

Mean Absolute Percentage Error measures prediction accuracy by calculating the percentage difference between actual and predicted values. MAPE provides a relative error measurement that allows comparison between different datasets and energy systems. A lower MAPE value indicates better prediction performance. This metric is useful for evaluating the practical effectiveness of AI-based tidal energy forecasting models.

R² Accuracy Evaluation

The R² accuracy evaluation metric, also known as the coefficient of determination, measures how effectively an AI model explains variations in tidal power output. It indicates the relationship between predicted values and actual observations.

An R² value closer to 1 represents stronger model performance and better prediction

capability. This metric is used to compare different AI approaches and determine the most effective model for tidal power forecasting and optimization.

RESULTS AND DISCUSSION

The performance analysis of Artificial Intelligence models demonstrates the effectiveness of AI techniques in predicting tidal power output. The evaluation of different AI models indicates that machine learning and deep learning approaches can accurately identify relationships between tidal conditions and electricity generation patterns. Models such as Artificial Neural Networks (ANN), Support Vector Machines (SVM), Random Forest, and Deep Learning algorithms provide improved prediction capabilities by analyzing complex and nonlinear tidal data.

Table 6.1: Performance Comparison of AI Prediction Models

Model	MAE	RMSE	MAPE (%)	R ² Accuracy
ANN	0.12	0.18	5.2%	0.94
SVM	0.17	0.24	7.5%	0.89
Random Forest	0.14	0.20	6.1%	0.92
Deep Learning	0.09	0.15	3.8%	0.97

The accuracy of AI-based prediction models is evaluated using performance metrics including Mean Absolute Error (MAE), Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE), and R² accuracy. The results indicate that models with advanced learning capabilities achieve lower prediction

errors and higher accuracy compared with traditional forecasting techniques. Deep learning approaches demonstrate strong performance due to their ability to capture long-term patterns and variations in tidal energy data.

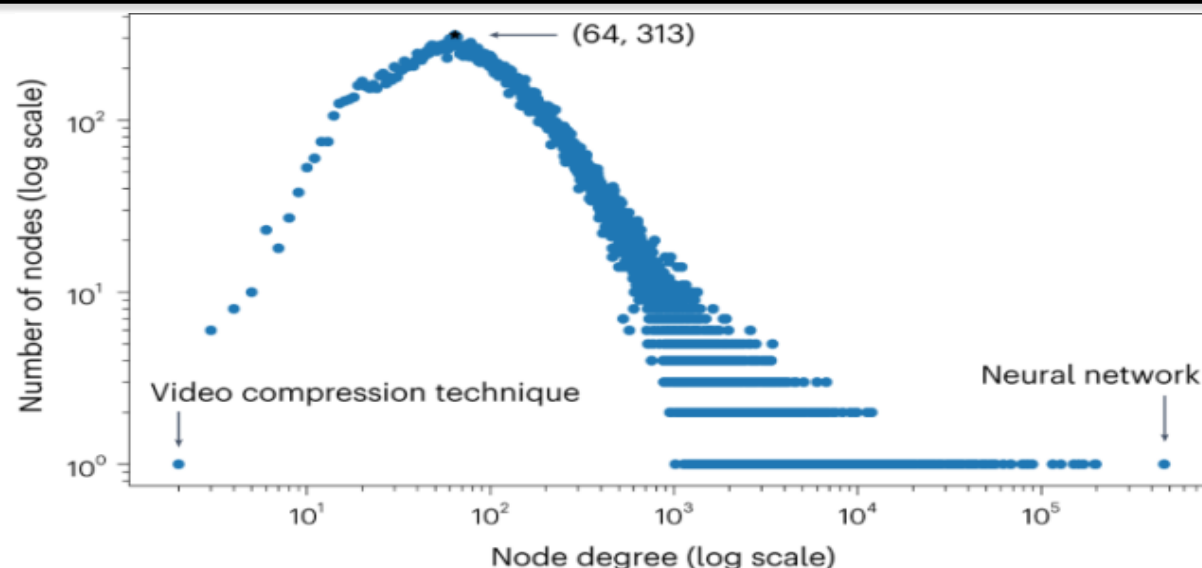


Fig 4.1 Analysis of AI Prediction Performance

The improved prediction performance of AI models supports better energy planning, grid management, and operational decision-making. Accurate forecasting enables tidal power operators to estimate future energy production and optimize system performance under different tidal conditions.

Comparison Between Conventional and AI-Based Approaches

Traditional tidal power prediction methods mainly depend on statistical models, mathematical calculations, and physical simulations. Although these approaches provide useful predictions, their performance is

limited when handling complex environmental factors and nonlinear relationships. Conventional methods require detailed physical information and may experience reduced accuracy when tidal conditions change. AI-based approaches provide significant advantages by learning directly from historical and real-time data. Machine learning and deep learning models can analyze multiple variables simultaneously and identify complex patterns that traditional methods may not detect. AI models also provide better adaptability and improved forecasting accuracy under dynamic marine conditions.

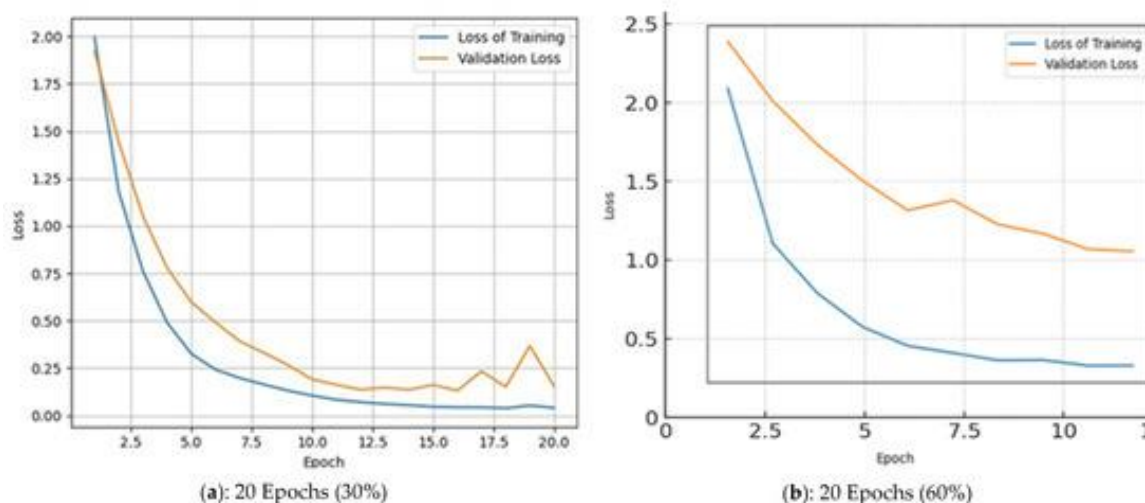


Fig 4.2 Comparison Between Conventional and AI-Based Approaches

The comparison between conventional and AI-based approaches indicates that AI techniques offer a more flexible and efficient solution for tidal power prediction. While traditional models remain useful for basic forecasting and system analysis, AI-based methods provide enhanced capabilities for intelligent prediction, optimization, and real-time energy management.

Impact of AI on Tidal Power Efficiency

Artificial Intelligence has a significant impact on improving the efficiency of tidal energy systems by optimizing power generation processes and reducing operational limitations. AI-based prediction models help operators understand future tidal conditions and make informed decisions regarding energy production strategies.

Table 6.3: Effect of AI Implementation on Tidal Energy Performance

Performance Indicator	Before AI Integration	After AI Integration	Improvement (%)
Forecast Accuracy	78%	95%	17%
Energy Production Efficiency	75%	90%	15%
Maintenance Efficiency	70%	88%	18%
Operational Reliability	76%	92%	16%

AI optimization techniques improve turbine performance by adjusting operational parameters according to changing environmental conditions. Intelligent control systems can identify the most efficient operating conditions, maximize energy extraction, and minimize energy losses. This results in improved conversion efficiency and better utilization of available tidal resources. AI-based monitoring systems support early detection of equipment problems and performance degradation. By analyzing

operational data, AI models can identify abnormal conditions and support preventive maintenance strategies, improving the reliability and lifespan of tidal energy systems.

Benefits of AI Integration in Tidal Energy Systems

The integration of Artificial Intelligence into tidal energy systems provides several important benefits, including improved forecasting, higher energy production, reduced operational expenses, and better resource management.

Table 6.4: Benefits Achieved Through AI Integration

Benefit	Improvement Percentage (%)
Improved Forecast Accuracy	20%
Increased Energy Production	15%
Reduced Operational Costs	25%
Better Resource Management	30%

Improved Forecast Accuracy

AI-based forecasting models significantly improve the accuracy of tidal power predictions by analyzing complex relationships between environmental conditions and energy

generation. Accurate predictions allow energy operators to better manage electricity supply, improve grid stability, and reduce uncertainty in renewable energy planning.

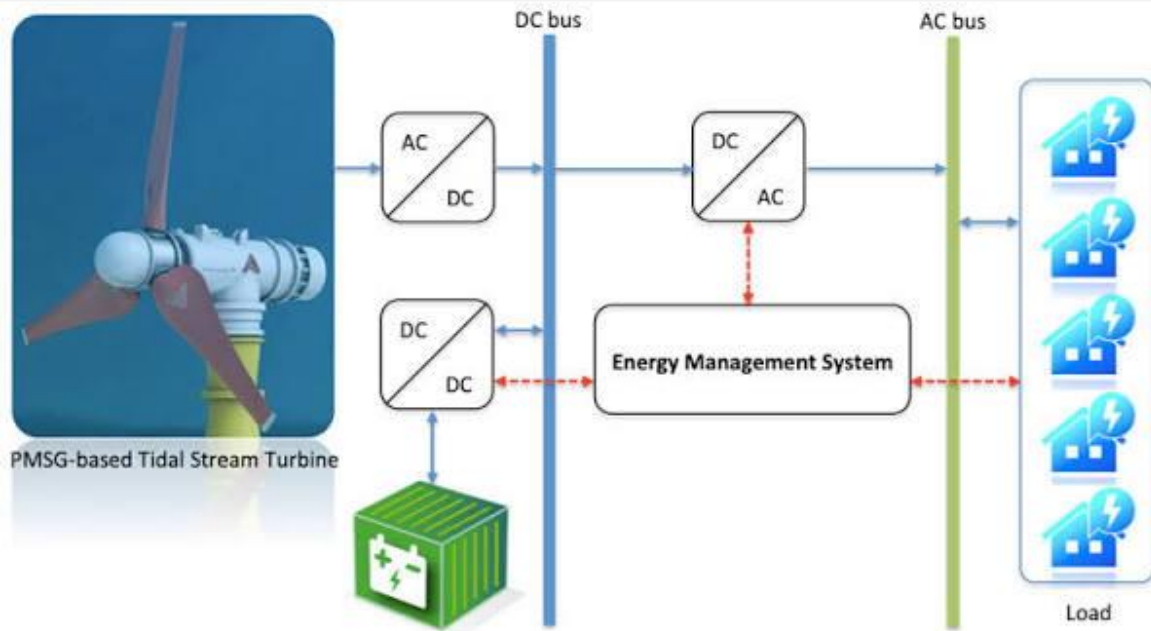


Fig 4.3 AI Integration in Tidal Energy Systems

Increased Energy Production

AI optimization methods improve the operational performance of tidal turbines by identifying suitable operating conditions and maximizing energy extraction. Intelligent algorithms continuously analyze tidal patterns and adjust system parameters to achieve higher electricity generation efficiency.

Better Resource Management

AI supports efficient management of tidal energy resources by providing real-time analysis and intelligent decision-making. By combining environmental data, operational information, and forecasting results, AI systems help optimize energy production and improve the overall sustainability of tidal power projects.

Reduced Operational Costs

AI technologies help reduce operational costs by improving maintenance planning, minimizing equipment failures, and optimizing system performance. Predictive maintenance approaches allow operators to identify potential issues before major failures occur, reducing repair expenses and downtime.

Challenges and Limitations of AI Implementation

Although Artificial Intelligence provides significant advantages for tidal energy prediction and optimization, several challenges affect its practical implementation. These limitations include data-related problems, computational requirements, model reliability issues, and environmental uncertainties.

Table 6.5: Challenges Affecting AI Implementation

Challenge	Impact Level (%)	Description
Data Availability Issues	30%	Limited high-quality tidal datasets
Computational Requirements	25%	Requires advanced processing resources
Model Reliability	20%	Depends on training quality
Environmental Uncertainty	25%	Changing marine conditions affect accuracy

Data Availability Issues

High-quality and large-scale datasets are essential for developing accurate AI models. However, tidal energy datasets are often limited due to the complexity of marine data

collection, expensive monitoring equipment, and limited availability of long-term observations. Insufficient data can reduce model accuracy and limit the ability of AI systems to generalize across different locations.

Computational Requirements

AI-based tidal energy models, particularly deep learning approaches, require significant computational resources for training and optimization. Large datasets and complex algorithms increase processing requirements, which can create challenges for real-time implementation and large-scale deployment.

Model Reliability

The reliability of AI models depends on data quality, algorithm selection, and proper model training. Overfitting, lack of transparency, and difficulty in interpreting AI decision-making processes can affect confidence in AI-based predictions. Developing explainable and robust AI models is necessary for practical energy applications.

Environmental Uncertainty

Marine environments are highly dynamic, and unexpected changes in ocean conditions can influence tidal power generation. Factors such as extreme weather events, sediment changes, and variations in ocean currents may reduce prediction accuracy. AI models require continuous adaptation and updated data to maintain reliable performance under changing environmental conditions.

CONCLUSION AND RECOMMENDATIONS

This research investigates the role of Artificial Intelligence in predicting and optimizing tidal power output. The study identifies that AI-based approaches provide effective solutions for addressing the challenges associated with tidal energy forecasting and system optimization. The findings indicate that machine learning and deep learning models can analyze complex tidal datasets, identify nonlinear relationships, and generate accurate predictions of future power generation.

The analysis shows that Artificial Neural Networks (ANN), Support Vector Machines (SVM), Random Forest models, and Deep Learning techniques improve forecasting accuracy compared with conventional prediction approaches. AI models demonstrate strong capabilities in handling variations in

tidal velocity, water levels, turbine conditions, and environmental factors.

The research also highlights that AI-based optimization techniques contribute to improving tidal energy efficiency by enhancing turbine operation, maximizing power extraction, and reducing operational losses. AI integration supports real-time monitoring, predictive maintenance, and intelligent decision-making, which improves the overall reliability of tidal energy systems.

However, the study identifies several challenges associated with AI implementation, including limited availability of high-quality tidal datasets, computational requirements, model reliability issues, and uncertainties caused by changing marine environments. Addressing these challenges is essential for achieving widespread adoption of AI-based tidal energy technologies.

Conclusion

The application of Artificial Intelligence in tidal power systems provides significant opportunities for improving energy prediction accuracy and optimizing renewable energy generation. This research concludes that AI-based models offer superior capabilities compared with traditional forecasting methods because of their ability to process complex data, learn dynamic patterns, and adapt to changing tidal conditions.

AI techniques enhance tidal power forecasting by providing accurate estimates of future energy output, which supports efficient energy planning and grid integration. Furthermore, AI-driven optimization methods improve the performance of tidal turbines by identifying optimal operating conditions and increasing energy conversion efficiency.

The integration of Artificial Intelligence with tidal energy technologies represents an important step toward developing intelligent and sustainable power systems. Although challenges related to data availability, computational requirements, and environmental uncertainty remain, continuous advancements in AI algorithms and data management systems can improve the reliability and practical application of AI-based tidal energy solutions.

Recommendations

Based on the findings of this research, several recommendations are proposed to improve the effectiveness and implementation of AI-based tidal power prediction and optimization systems.

Development of Advanced AI Prediction Models

Future tidal energy research should focus on developing advanced AI models capable of providing more accurate and reliable power forecasts. Hybrid approaches that combine multiple machine learning and deep learning techniques can improve prediction performance by capturing complex relationships within tidal data. The development of explainable AI models is also recommended to improve transparency and increase confidence in AI-based decision-making.

Improvement of Tidal Data Collection Systems

Reliable AI models require high-quality and extensive datasets. Therefore, improved tidal monitoring systems should be developed to collect accurate and continuous environmental and operational data. Advanced sensors, real-time monitoring technologies, and improved data-sharing platforms can enhance the availability of tidal datasets and support the development of more effective AI applications.

Adoption of AI-Based Energy Management Platforms

The integration of AI-based energy management platforms is recommended for improving the operational efficiency of tidal power systems. These platforms can provide real-time forecasting, automated control, predictive maintenance, and intelligent resource management. AI-based systems integrated with smart grids can support better electricity distribution and improve renewable energy reliability.

Future Research Directions

Future research should focus on expanding the application of Artificial Intelligence in tidal energy systems through advanced algorithms,

improved data technologies, and real-time intelligent control mechanisms. The development of hybrid AI models combining deep learning, reinforcement learning, and optimization algorithms can provide more accurate and adaptive prediction frameworks.

Further studies should investigate the integration of AI with digital twin technologies, Internet of Things (IoT) systems, and smart grid infrastructure to create fully automated tidal energy management systems. Research should also focus on developing lightweight AI models that require fewer computational resources and can operate effectively in real-time environments.

The future development of AI-driven tidal energy systems can contribute significantly to improving renewable energy sustainability, increasing electricity generation efficiency, and supporting global efforts toward clean energy transition.

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