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Review on Applications of Artificial Intelligence and Machine Learning on Hydro power generation

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ABSTRACT:

This review paper explores the significant influence of Artificial Intelligence (AI) and Machine Learning (ML) on the hydropower sector, emphasizing their potential to transform energy generation. By enabling real-time monitoring, predictive maintenance, and data-driven decision-making, these technologies improve operational efficiency and reliability. The use of AI and ML not only reduces equipment downtime but also enhances power generation processes, resulting in better management of hydropower resources. Additionally, the adoption of AI and ML supports environmental sustainability by ensuring that energy production aligns with ecological preservation objectives. These intelligent systems assist in minimizing the environmental impact of hydropower operations while complying with regulatory requirements. As the demand for renewable energy grows, the integration of these advanced technologies offers a future where hydropower is not only more efficient but also more considerate of our planet's health. This paper underscores the essential role of AI and ML in developing a sustainable and resilient hydropower industry.

Key words: ANN, Fuzzy logic, SOM, Support vector mapping, Gaussian process regression

Introduction:

Artificial Intelligence (AI) and Machine Learning (ML) are transforming hydropower generation by serving as smart tools that improve efficiency, reliability, and environmental sustainability. These technologies use advanced algorithms to monitor power systems in real-time, anticipate maintenance needs, and enhance electricity generation from water. Beyond just technological improvements, AI and ML support informed decision-making, ensuring that hydropower operations are effective and environmentally responsible.

In practice, AI and ML act as proactive problem-solvers, sifting through large volumes of data to spot potential issues early and avert unexpected failures. They optimize water resource usage for electricity generation, adjusting to changing conditions like water flow and weather patterns. Crucially, these technologies emphasize ecological considerations, helping to reduce the environmental footprint of hydropower and ensuring adherence to regulations. Overall, AI and ML function as environmentally conscious allies in the energy sector, fostering a future for hydropower that is both efficient and sustainable.

Methodologies:

1.Self-Organizing Map(SOM):

Self-Organizing Map (SOM) can assist hydropower plants in gaining insights into the silt patterns present in their reservoirs throughout the year. Silt consists of tiny particles in the water that can lead to various issues. Unlike other computational methods, SOM does not focus on correcting errors; instead, it allows data points to "compete" and organize themselves based on their similarities. This approach helps maintain the essential relationships between the data. The diagram illustrates how SOM operates, comparing data points to identify the best matches. For instance, at the MB-II hydropower plant located in the Himalayan region, it was observed that silt levels peak from April to September, with particularly high levels in July and August. If silt concentrations exceed a certain threshold, they can damage the plant's machinery. Therefore, the plant is utilizing SOM to analyze a year's worth of Twin Support Vector Regression (TSVR) information, transforming it into a practical map. This enables the plant to predict and comprehend silt patterns, thereby preventing potential harm to the equipment.

2.The Fuzzy Clustering Iteration (FCI):

The Fuzzy Clustering Iteration (FCI) method plays an essential role in fuzzy mathematics and is often used to investigate nonlinear relationships between a target variable and its influencing factors. This method employs a fuzzy membership function for the analysis. The approach involves working with a dataset containing n samples, each characterized by m variables, which are organized in a matrix format. The data matrices are clustered, and the process iterates to derive the complex calculations needed.

3.Twin Support Vector Regression (TSVR):

The Twin Support Vector Regression (TSVR) method is an effective approach grounded in structural risk minimization theory, specifically designed to tackle nonlinear regression challenges. TSVR is presented as an enhancement over the traditional Support Vector Regression (SVR), which often proves to be computationally demanding and requires significant memory when dealing with large training datasets. By formulating two quadratic programming problems, TSVR effectively addresses the shortcomings of SVR, leading to improved computational efficiency.

4.Methodology for water level forecasting:

The forecasting model uses four machine learning algorithms: Boosted Decision Tree Regression (BDTR), Decision Forest Regression (DFR), Neural Network Regression (NNR), and Bayesian Linear Regression (BLR). BDTR is an ensemble method that corrects errors in a sequential manner, making it particularly effective for tabular data. DFR consists of a collection of decision trees that are trained randomly, which helps it resist overfitting, although it is less interpretable. NNR employs nonlinear activation functions and hidden layers for regression tasks, making it suitable for problems where traditional models may struggle. BLR applies Bayesian Inference, integrating prior information about parameters with a likelihood function to estimate those parameters, offering a variety of inferential solutions.

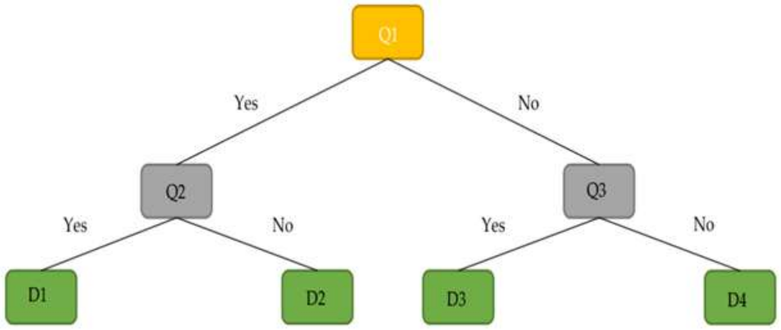

Figure 1- Boosted decision tree regression

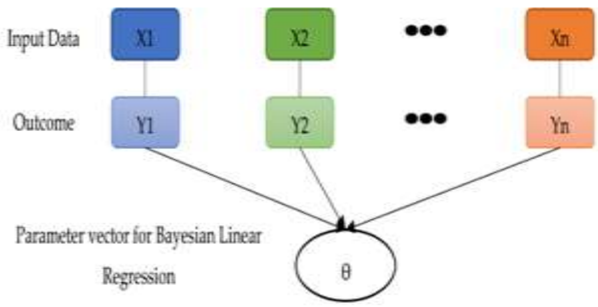

Figure 2- Decision forest regression

BDTR, DFR, NNR, and BLR each possess unique characteristics and benefits. For instance, BDTR is recognized for its resilience to missing data and its ability to assign significance scores to features, whereas DFR is effective against overfitting and shows reduced classification errors. NNR, commonly utilized in deep learning, is capable of adapting to regression tasks with intricate patterns. BLR, which relies on Bayesian Inference, is particularly adept at handling insufficient or poorly distributed data.

The selection of these methods is based on the difficulty of replicating the water level process, which is affected by a range of random and natural factors such as reservoir inflow patterns and evaporation rates. Conventional models often find it challenging to address these complexities, which is why machine learning techniques present a promising alternative for precise water level predictions.

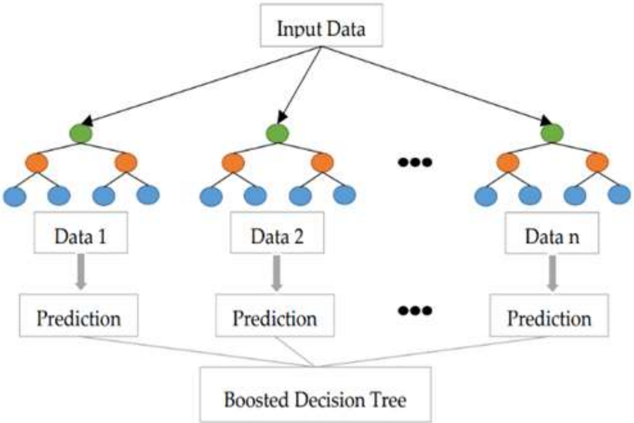

Figure 3-Bayesian linear regression

5.Artificial Neural Networks (ANN):

Artificial Neural Networks (ANN) are advanced mathematical models that find applications in various domains, including finance, geology, medicine, engineering, and physics. These networks are made up of interconnected neurons, each possessing local memory, which enables them to tackle complex problems by recognizing relationships among different variables. In this study, we employ a multilayer Feed-forward ANN, known for its effectiveness in addressing real-world challenges. The Feed-forward architecture allows signals to flow sequentially from input to hidden units and then to output units, ensuring stability and fault tolerance. Neurons are arranged in separate layers, with direct connections between them, creating a feedforward structure. The selected configuration features a fully connected network, where input values kick off the process and move through hidden and output layers, producing results through activation functions. The flexibility, robustness, and user-friendliness of ANN make it a preferred option over other statistical models, particularly in scenarios where the flow of information is critical.

Literature survey:

I. Di Zhang, Dongsheng Wang, Qidong Peng, Junqiang Lin, Tiantian Jin, Tiantian Yang, Soroosh Sorooshian, Yi Liu, Prediction of the outflow temperature of large-scale hydropower using theory-guided machine learning surrogate models of a high-fidelity hydrodynamics model,2022. In this study, researchers are employing sophisticated computer models, particularly machine learning, to forecast the temperature of water exiting the Jinping-I hydroelectric power plant in China. Understanding this temperature is vital as it can influence the downstream environment and the health of aquatic life. The findings are encouraging, indicating that the machine learning model can swiftly and accurately predict water temperature, aiding operators in effectively managing water intake facilities.

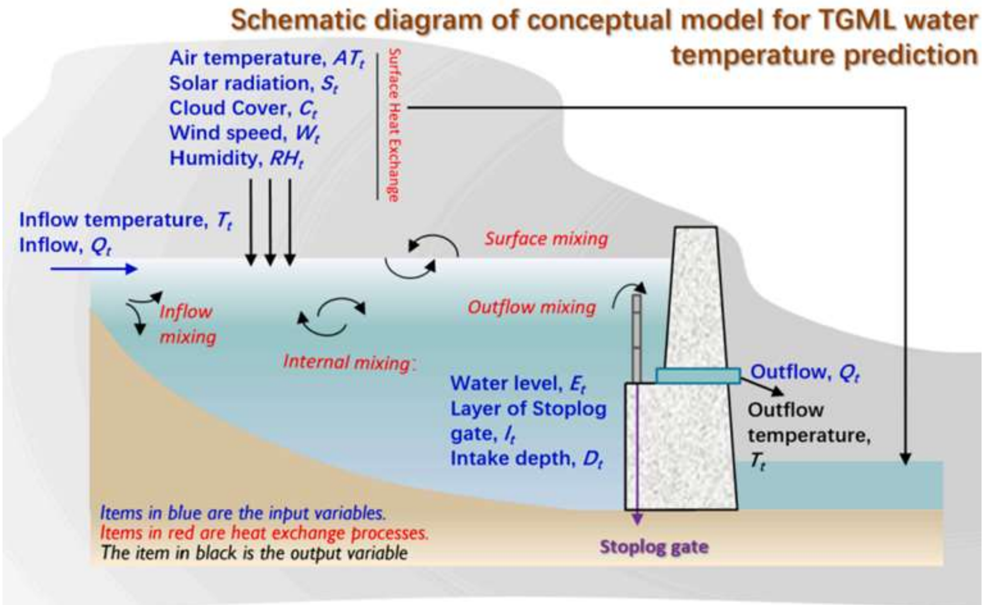

Figure 4-Artificial neural network

Hydropower, recognized as a clean and renewable energy source, is gaining significance in the 21st century. In China, large dams like Jinping-I are being constructed to satisfy the increasing energy demand. However, these dams can have environmental repercussions, particularly concerning water temperature, which can impact aquatic ecosystems. This study presents a novel method known as Theory-Guided Machine Learning (TGML) to enhance the accuracy and speed of water temperature predictions. The TGML framework integrates machine learning algorithms with data from computer models to train and forecast water temperatures, demonstrating exceptional computational efficiency. This innovative approach could enhance the operation of water intake facilities, not only at Jinping-I but potentially in other locations as well.

II. Zhong-kai Feng, Wen-jing Niu, Tai-heng Zhang, Wen-chuan Wang, Tao Yang, Deriving hydropower reservoir operation policy using data-driven artificial intelligence model based on pattern recognition and metaheuristic optimizer,2023. This article examines the use of machine learning techniques, such as artificial neural networks and support vector machines, to forecast hydropower generation based on data from a Chinese reservoir collected between 1979 and 2016. The authors evaluated various algorithms across different scenarios, including daily, monthly, and seasonal power production forecasts. Unlike traditional methods, machine learning excels at processing complex environmental and hydrological data, making it a valuable tool for energy decision-makers. The study centres on the Three Gorges Project in China, a significant hydropower facility, utilizing smart sensor data to analyse daily variations. The findings indicate that machine learning approaches are effective for predicting power output, providing benefits such as identifiable patterns and straightforward implementation. The research aims to enhance prediction algorithms by further optimizing their internal parameters.

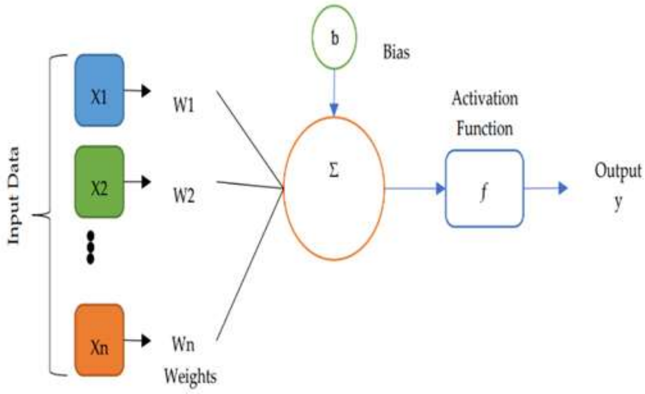

Figure 5-Schematic diagram of the conceptual model for TGML water temperature prediction

III. Krishna Kumar, R.P. Saini, Application of machine learning for hydropower plant silt data analysis,2021. When we refer to "hydropower plant silt data," we're discussing the measurements and records that indicate the amount of dirt and sediment that has accumulated at the bottom of the water storage area created by the hydropower plant. This information is crucial for the effective operation and maintenance of the plant, as excessive silt can impact its electricity generation efficiency.

Hydropower plants located in hilly regions, like the Himalayas, often face a challenge known as silt erosion, particularly during the monsoon season when heavy rainfall carries a significant amount of dirt and sediment. This silt can cause damage to the mechanical components of the hydropower plant. To address this issue, engineers can employ a machine learning technique called the Self-Organizing Map (SOM) algorithm. SOM is a type of artificial neural network that aids in organizing and visualizing data.

Figure 6-Erosion in 76 MW Francis turbine runner and guide vanes of MB-II Hydropower Plant

Hydropower is generally an efficient and cost-effective energy source. However, an excess of dirt and mud in the water can harm the machinery in these power plants, especially during the rainy season. To mitigate this, engineers and scientists utilize durable materials like stainless steel for the machinery. Researchers have also investigated how this sediment damages the equipment and ways to minimize its impact. Interestingly, they are leveraging machine learning to gain a better understanding of the sediment. These programs assist in organizing the sediment data and predicting potential future issues, allowing for proactive maintenance before any breakdowns occur.

IV. Zahid Masood, Shahroz Khan, Li Qian, Machine learning-based surrogate model for accelerating simulation-driven optimisation of hydropower Kaplan turbine,2021. This study aims to enhance the efficiency of hydroelectric power generation by refining the design of Kaplan turbines used in the process. Rather than depending on intricate and lengthy testing methods, the researchers developed an intelligent system that streamlines the turbine design process. They adopted a data-driven strategy, which simplified the complexity of the design space and utilized machine learning techniques such as Gaussian Process Regression. This innovative system was able to predict essential turbine performance metrics, leading to an optimal turbine design that boosted efficiency from 56.98% to an impressive 90.73%. This approach not only improves turbine performance but also lowers computational costs, presenting a promising avenue for sustainable hydropower production. In simpler terms, researchers discovered an innovative method for designing superior hydroelectric turbines. They made the design process easier by leveraging advanced technology and machine learning, which led to a significant increase in the turbines' efficiency while conserving time and resources. This new approach surpassed traditional methods and shows great potential for advancing sustainable hydropower in the future.

V. Karakatsanis, D.; Theodossiou, N. Smart Hydropower Water Distribution Networks, Use of Artificial Intelligence Methods and Metaheuristic Algorithms to Generate Energy from Existing Water Supply Networks. Energies 2022. The concept involves installing small hydraulic turbines in existing water supply systems to harness energy from daily fluctuations in water pressure. To achieve this, a network of five pressure sensors was established, linked to an AI system designed to predict pressure levels across the network. These sensors were strategically positioned at key points in the water system, utilizing math-based algorithms. Data was collected using EPANET (Environmental Protection Agency Network Evaluation Tool) software, followed by the application of an optimization algorithm known as Harmony Search to determine the optimal times for operating the turbines to maximize energy production. This method was tested on a sample water supply system, and the results were shared, highlighting efforts to utilize changes in water pressure for power generation in water networks.

VI. Sapitang, M.; M. Ridwan, W.; Faizal Kushiar, K.; Najah Ahmed, A.; El-Shafie, A. Machine Learning Application in Reservoir Water Level Forecasting for Sustainable Hydropower Generation Strategy. Sustainability 2020. This study focuses on predicting changes in water levels in a Malaysian reservoir, particularly during rainfall or other influencing factors. Researchers experimented with various computer programs to determine which one could most accurately forecast water levels. They discovered that a method known as "Boosted Decision Tree Regression" performed exceptionally well under specific conditions. This advancement could aid in managing water resources and mitigating flooding risks in the region. In simpler terms, scientists in Malaysia utilized advanced computer programs to estimate how much the water in a reservoir might fluctuate, especially during rain. They evaluated different programs and found that "Boosted Decision Tree Regression" excelled at predicting water levels, which is crucial for effective water management and flood prevention. This approach could be beneficial in addressing weather changes and ensuring adequate water supply in the reservoir.

VII. Ekaterina Gospodinova', Ivan Torlakov and Ivelina Metodieva,Increasing the Productivity of an Electricity System Based on Energy Generated by Hydropower with the Help of Artificial Intelligence 2023. This research aims to improve hydropower in Bulgaria by developing a model that addresses the unpredictable aspects of renewable energy. With abundant water resources, Bulgaria is well-positioned for energy generation, but renewable sources still lag behind traditional ones in terms of cost-effectiveness. The researchers are implementing advanced algorithms to optimize the capacity and design of hydroelectric power stations. Additionally, they are creating a prediction algorithm to enhance short-term energy demand forecasts, particularly during peak times of the day. The ultimate goal is to make renewable energy more competitive and sustainable in Bulgaria, taking into account both environmental impacts and economic viability.

VIII. Krishna Kumar, R. P. Saini,Application of Artificial Intelligence for the Optimization of Hydropower Energy Generation,2021 Hydropower is an excellent method for generating electricity from water, but it requires significant construction and careful planning to function effectively. The performance of hydropower plants relies on factors such as the volume of water and the height of the water source. It's essential to tackle challenges like maintaining machinery and preventing erosion. Advanced technologies, including Artificial Intelligence (AI) and techniques like artificial neural networks and fuzzy logic, are crucial for forecasting energy demand, enhancing plant efficiency, and overcoming various obstacles. As we harness renewable energy sources like hydropower, AI helps manage their often unpredictable characteristics, ensuring that power systems remain reliable and safe through real-time monitoring.

IX. Marwah Sattar Hanoon, Ali Najah Ahmed, Arif Razzaq, Atheer Y. Oudah , Ahmed Alkhayyat ,Yuk Feng Huang, Pavitra kumar , Ahmed El-ShafiePrediction of hydropower generation via machine learning algorithmsat three Gorges Dam, China,2021. This study investigates the use of advanced computer programs known as machine learning to forecast the power output of a Chinese reservoir from hydropower. Researchers evaluated various algorithms, including artificial neural networks and support vector machines, to determine which ones excel in predicting daily, monthly, and seasonal energy generation. Unlike conventional methods, these algorithms can manage complex relationships within environmental and water data. The focus is on the Three Gorges Project in China, a significant source of hydropower, demonstrating that machine learning can effectively aid decision-making in the energy sector. The findings indicate that both artificial neural networks and support vector machines are effective for hydropower predictions, with plans to enhance these forecasts in the future.

X. Piyal Ekanayake , Lasini Wickramasinghe , J. M. Jeevani W. Jayasinghe ,and Upaka Rathnayake Regression-Based Prediction of Power Generation at Samanalawewa Hydropower Plant in Sri Lanka Using Machine Learning 2021,Volume 2021. This paper examines the potential for power generation at Sri Lanka's Samanalawewa hydropower plant using advanced computer modeling techniques. Researchers evaluated rainfall, temperature, and evaporation data from 1993 to 2019 to predict energy output. The results showed that some rainfall locations are more critical than others, and various models, such as Gaussian process regression and support vector regression, were utilized to improve prediction accuracy. This research is vital for planning the clean energy production of the hydropower plant, particularly given the increasing global demand for sustainable energy. Furthermore, the study highlighted the impact of climate change on water availability and power generation, emphasizing the need for dependable prediction models to ensure a stable and eco-friendly energy supply.

Conclusions:

The use of Artificial Intelligence (AI) and Machine Learning (ML) in hydropower systems has transformed energy production by improving both efficiency and reliability. These technologies allow for accurate predictive modeling of water levels, reservoir inflows, and energy generation, enabling operators to make well-informed decisions in response to changing climate conditions. Additionally, AI enhances plant operations through sophisticated algorithms that optimize capacity and design, while smart technologies like the Internet of Things (IoT) provide real-time monitoring to tackle issues such as fluctuating production rates and water quality. Ultimately, this combination not only guarantees dependable power generation but also aids in the shift towards cleaner, more sustainable energy solutions, making hydropower systems more resilient and adaptable to future challenges.

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