A Hybrid Model of Particle Swarm Optimization for Wind Energy and Wind Power Through RNN

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ABSTRACT
The increasing demand for sustainable energy sources has led to a great deal of study on optimizing wind energy systems. This study proposes a hybrid model that combines recurrent neural networks (RNN) and particle swarm optimization (PSO) to increase the efficiency of wind power forecasting and energy generation. Using previous data and meteorological conditions, the RNN is used to anticipate wind power output. The RNN's parameters are optimized via the PSO algorithm. The suggested model addresses the variable and irregular character of wind patterns in an effort to maximize energy output and enhance wind power forecasts through the integration of many methodologies. The hybrid model's performance is evaluated using actual wind farm data; the findings demonstrate a significant improvement in forecast accuracy and computing efficiency over traditional methods. This work demonstrates how advanced computational techniques and machine learning models can be used to enhance renewable energy systems and contribute to the development of safer and more effective wind energy solutions.

Keywords - Particle Swarm Optimization, Recurrent Neural Networks, Wind Energy, Wind Power Forecasting, Renewable Energy

I. INTRODUCTION

Effective models are required to maximize energy generation and distribution due to the rising demand for renewable and sustainable energy sources. A key component in solving the world's energy problems is wind energy, which is among the most plentiful and affordable renewable energy sources. But because wind power output is unpredictable and weather-dependent, it is difficult to forecast with any degree of accuracy. In order to improve forecasting accuracy and maximize wind turbine energy output, machine learning and optimization approaches have become crucial. Recurrent neural networks, or RNNs, have demonstrated significant potential in recent years for modeling time-series data, which makes them ideal for predicting wind power and speed. However, RNNs need precise parameter settings and effective feature selection—often accomplished through optimization techniques—to perform at their best in wind energy forecasting. Particle Swarm Optimization (PSO) has shown itself to be a successful optimization technique for optimizing machine learning models; but, by incorporating other techniques, its efficacy can be further increased. By integrating Harmony Search with a Meta-Heuristic method, this study presents a Hybrid Model of Particle Swarm Optimization for optimizing parameters in RNN-based wind energy forecast models. Exploring complex parameter spaces is made easier by the Harmony Search algorithm's unique improvisation process. The meta-heuristic method ensures a balanced search for the best answers by augmenting the PSO's exploration and exploitation capabilities. Through the use of this hybrid optimization model, our study seeks to increase wind power forecasting's precision and dependability. As a result, wind energy will be more effectively incorporated into the electrical grid, improving energy sustainability and stability. This model provides a foundation for more robust and effective renewable energy systems by addressing the challenges of wind energy forecasting in a novel way. Natural language processing, time-series forecasting, and other applications involving data with temporal dependencies are especially well-suited for Recurrent Neural Networks (RNNs), a kind of artificial neural networks created especially for processing sequential data. RNNs feature a special architecture that enables them to remember information about prior inputs, capturing relationships and patterns across time, in contrast to typical feedforward neural networks, which handle each input separately. The social behavior of schools of fish and flocks of birds served as the inspiration for the popular optimization algorithm known as particle swarm optimization (PSO). PSO is a population-based, meta-heuristic method that was created by Eberhard and Kennedy in 1995 and has shown promise in resolving challenging, multi-dimensional optimization issues. Based on both individual and collective experience, the algorithm works with a collection of possible solutions, or particles, that "swarm" through the solution space in pursuit of the optimal answer.

Every particle in PSO is a candidate solution, and its movement is determined by its velocity and position in the search space. Two important criteria are used by particles to iteratively update their positions: their personal best-known position (individual knowledge) and the best-known position of all the particles in the swarm (social knowledge).

II. LITERATURE SURVEY

1. Multiple Wind Speed Forecast Using Simple Recurrent Unit [2023]

The study discusses the difficulty of incorporating intermittent wind power into electricity systems. Conventional forecasting techniques, such as statistical and physical models, frequently have accuracy issues. Since recurrent neural networks (RNNs) are better suited for time-series data and can understand intricate correlations between numerous parameters, such weather patterns and turbine efficiency, the study suggests utilizing RNNs for wind power forecasting.When trained on historical wind power and meteorological data, the suggested RNN-based model demonstrated a notable increase in accuracy above conventional feedforward neural networks (FFNNs). According to the study's findings, using this strategy could boost wind power systems' efficiency and facilitate better energy industry decision-making.

2. A Hybrid Statistical Model for Ultra Short Term Wind Speed Prediction [2023]

The study's key conclusion is that the proposed hybrid model (SARIMAX-RNN-SVR) significantly enhances wind speed predictions compared to individual models. This improvement is largely due to the model's capacity to capture temporal patterns and account for both linear and nonlinear relationships in wind speed data. According to the experimental results, the hybrid model outperforms the standalone SARIMAX, RNN, and SVR models across several evaluation metrics, including Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and Mean Square Error (MSE).

3. Short-term Wind Speed Forecasting Using Multi-Source Multivariate RNN-LSTMs [2021]

The study demonstrates that utilizing multiple sources of input data significantly enhances the accuracy of wind speed forecasts compared to traditional univariate models. It provides a comparative analysis of different forecasting models, including ARIMA and RNN-LSTM.The results indicate that the multivariate RNN-LSTM model outperforms both univariate models and traditional statistical methods in terms of forecasting accuracy.

4. Recurrent Neural Network Based Efficient Short-Term Wind Power Forecasting[2023]

This study suggests a recurrent neural network (RNN) based wind power forecasting system that makes use of weather information, historical wind power data, and other pertinent factors to estimate wind power generation in the future. Because it more effectively utilizes non-linearity, the RNN is a superior substitute for the feed forward neural network. The created system may increase wind power systems' efficiency and facilitate improved energy sector decision-making.

5. Short-term wind speed prediction based on combinatorial prediction model[2023]

The rapid decline of non-renewable resources and environmental concerns are the main reasons behind the growing emphasis on renewable energy sources, especially wind energy. Wind energy's inherent intermittency and volatility necessitate accurate wind speed predictions to mitigate operational risks in power systems.Models of artificial intelligence, statistics, and physics are used to classify traditional forecasting approaches. While physical models are suitable for long-term forecasting, they are computationally intensive. Statistical models, like Autoregressive models, are simpler but often lack accuracy. In contrast, artificial intelligence models, especially deep learning approaches, have emerged as effective solutions, addressing the limitations of shallow learning algorithms

6. Wind Speed Prediction Based on Gate Recurrent Unit[2022]

For the purpose of improving wind speed forecasting accuracy and handling irregular, variable, and irregular wind speed, this work presents a hybrid forecasting model called the mixed-mode decomposition approach (EEMD-VMD), which divides the wind speed sequence into several sub-modes (IMFs). Each sub-modality's neural network structure is optimized using a particle swarm optimization technique, and each sub-modality's feature learning and prediction are handled by a deep neural network GRU.

7. Stochastic Modeling for Wind Energy and Multi-Objective Optimal Power Flow by Novel Meta-Heuristic Method[2021]

The Weibull distribution parameters are found in this paper using two unique artificial intelligence (AI) algorithms: the Aquila Optimizer (AO) and the Mayfly algorithm (MA). These results are compared with four classical numerical techniques: Maximum Likelihood Approach, Energy Pattern Factor Method, Graphical Method, and Empirical Method. When analyzing the two-parameter Weibull distribution, the two AI algorithms show their superiority and robustness by yielding reduced errors and higher correlation coefficients.

8. Maximum Power Point Tracking for Wind Power Generation System at Variable Wind Speed using a Hybrid Technique[2015]

This paper presents the combined Wind Energy Conversion System (WECS) with Permanent Magnet Synchronous Generator (PMSG) and PSO-RNN controller. By merging the Particle Swarm Optimization (PSO) method with a Recurrent Neural Network (RNN), the proposed hybrid technique generates the optimal dc reference current. The suggested Maximum Power Point Tracking (MPPT) approach uses the power curve to identify the maximum operating point, which is reliant on the dc link voltage and current.

9. A Short-Term Wind Speed Forecasting Model Based on EMD/CEEMD and ARIMA-SVM Algorithms[2021]

The support vector machine (SVM), auto-regressive integrated moving average (ARIMA), and complementary ensemble empirical mode decomposition (CEEMD) are combined in this study to create a novel short-term wind speed forecasting model. First, EMD and CEEMD are used to decompose the recorded wind speed sequence into a finite number of intrinsic mode functions (IMFs) and a decomposed residual. Every IMF subseries has better linear characteristics. The ARCA algorithm is used to predict each subseries. After that, a new subseries is constructed by summing up all of the projected errors for each subseries.

10. Short-Term Wind Power Forecasting in East Java using Gated Recurrent Unit [2023]
This study introduces a method for forecasting wind turbine power output by predicting wind speed using the Gated Recurrent Unit (GRU). GRU, a variant of Recurrent Neural Networks (RNN) similar to Long Short-Term Memory (LSTM), offers a more streamlined structure and improved training efficiency. Based on simulations using the M2T1NXSLV dataset, the GRU model—trained with a 24-hour time lag, 50 epochs, and external inputs like temperature, pressure, and humidity—produced highly accurate predictions, achieving a Mean Absolute Error (MAE) of 0.107 m/s and a Mean Absolute Percentage Error (MAPE) of 8.06%. This performance exceeded that of the LSTM model, which was trained with the same settings, except for the number of epochs (40), where it obtained an MAE of 0.109 m/s and a MAPE of 8.22%.

III. RESULT AND CONCLUSION

The proposed hybrid model, combining Meta-Heuristic Particle Swarm Optimization (PSO) and Harmony Search with Recurrent Neural Networks (RNN), was evaluated using actual wind energy data. Accurate Prediction Prediction accuracy for the hybrid PSO-Harmony Search RNN system showed an important increase. Better-tuned RNN models resulted from a more extensive investigation of a hyper parameter space made possible by Harmony Search's creation into the PSO framework. Efficiency of Optimization the PSO algorithm's addition of Harmony Search greatly improved the optimization process, allowing the model to break free from local optimal conditions and discover larger-scale solutions. The durability and Communication Strong stability has been shown by the hybrid model over a range of meteorological events and data sets, allowing it to efficiently apply to previously unknown situations. This flexibility is attributed to the complementing impact of Harmony Search and Meta-Heuristic PSO, which together provided a more adaptable and flexible optimization process. Even under extremely changeable wind conditions, the model maintained a high level of prediction accuracy, proving that it can be used in real-world situations.

This paper established a novel hybrid model to enhance wind power forecasting by merging Meta-Heuristic Particle Swarm Optimization (PSO), Harmony Search, and Recurrent Neural Networks (RNN). The outcomes demonstrated that the hybrid model outperformed standard RNN models and conventional optimization techniques in terms of prediction accuracy and computing efficiency. The model was able to predict wind output more reliably and correctly by combining these two elements, which is crucial for maximizing wind energy production and preserving grid stability. The suggested hybrid model showed noteworthy computational benefits in addition to increasing the precision of wind power projections, making it a workable option for real-time applications. The model's success highlights how hybrid optimization techniques can be used to forecast renewable energy. This paper offers a methodology for creating robust forecasting models that can take into account the unpredictability of renewable energy sources by fusing optimization techniques with machine learning models like RNNs. Reducing dependency on non-renewable energy sources and promoting environmental sustainability are two of the research's wider ramifications. To handle even more complicated datasets, future research can concentrate on extending this hybrid model by adding more deep learning architectures or optimization methods. These additions might enhance the model's suitability for other renewable energy sources, such solar and hydroelectric power, and make it a useful tool for a number of industries within the renewable energy sector.

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