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Optimizing Wind Power Forecasting With A Novel Hybrid Metaheuristic Approach: A Different Speed Case Study

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ABSTRACT: Wind power forecasting plays a critical role in the efficient integration and management of wind power plants, particularly in different speed settings where wind conditions can vary significantly. In this study, we propose a novel hybrid metaheuristic approach to optimize wind power forecasting in a different speed context. The approach combines the Particle Swarm Optimization (PSO) algorithm and the Gravitational Search Algorithm (GSA) to enhance forecasting accuracy and efficiency. We collect real-world wind power data from multiple locations, including meteorological variables and relevant parameters. The GSA algorithm is utilized for feature selection, identifying the most important features to improve forecasting performance. Subsequently, the PSO algorithm optimizes the forecasting model's parameters to minimize the error between predicted and actual wind power values. The proposed hybrid metaheuristic approach is compared with conventional forecasting models, and its performance is evaluated using various metrics. Results demonstrate that the hybrid approach outperforms existing models in terms of accuracy, robustness, and computational efficiency. The study's findings provide valuable insights into the application of metaheuristic algorithms for wind power forecasting and contribute to the broader field of metaheuristic optimization and renewable energy research. The proposed approach holds great potential for enhancing wind power forecasting in different speed scenarios, facilitating better integration of wind power into the electricity grid, and promoting the efficient utilization of renewable energy resources.

KEYWORDS: metaheuristic, Hyperbolic tangent sigmoid transfer function, Linear transfer function

I. INTRODUCTION

The integration of renewable energy sources, particularly wind power, into the electricity grid has gained significant attention in recent years. Wind power offers a clean and sustainable alternative to traditional fossil fuel-based generation methods, contributing to the reduction of greenhouse gas emissions and addressing the challenges posed by climate change. However, the intermittent and variable nature of wind poses significant challenges for the reliable and efficient integration of wind power into the grid. Accurate forecasting of wind power generation is crucial for optimal grid management, energy scheduling, and system stability. Effective wind power forecasting enables grid operators to anticipate fluctuations, plan energy production and consumption, and optimize the utilization of available resources. Various forecasting techniques, ranging from statistical models to machine learning algorithms, have been explored to improve wind power forecasting accuracy. However, there is still room for further enhancements to achieve more precise and reliable predictions.

In this study, we present a novel hybrid metaheuristic approach for optimizing wind power forecasting in a different speed context. Metaheuristic algorithms have shown promise in solving complex optimization problems by leveraging evolutionary principles and mathematical optimization techniques. By combining different metaheuristic algorithms, we aim to harness their complementary strengths to enhance the accuracy and robustness of wind power forecasting. Our proposed hybrid metaheuristic approach combines the bat algorithm and the particle swarm optimization algorithm to optimize the forecasting model's parameters and weights. The bat algorithm is inspired by the echolocation behavior of bats and is known for its exploration and exploitation capabilities, while the particle swarm optimization algorithm is inspired by social behavior and exhibits a collaborative search process. By leveraging the strengths of these algorithms, we aim to improve the overall performance of wind power forecasting. To evaluate the effectiveness of our hybrid metaheuristic approach, we

conduct a different speed case study using real-world wind power generation data from multiple locations. We compare the performance of our approach against other forecasting models, including traditional statistical models and machine learning algorithms commonly used in wind power forecasting. The findings from this study will contribute to advancing the field of wind power forecasting by providing insights into the efficacy of hybrid metaheuristic approaches in improving accuracy and reliability. Ultimately, enhancing the accuracy of wind power forecasting will enable grid operators and energy planners to make informed decisions, optimize resource allocation, and ensure the efficient integration of wind power into the electricity grid, further promoting the adoption of sustainable and renewable energy sources.

II. RELATED WORK

Several studies have focused on wind power forecasting using various modelling techniques and optimization algorithms. In this section, we review relevant literature that explores different approaches to wind power forecasting and optimization. Traditional statistical models, such as autoregressive integrated moving average (ARIMA) [19] and exponential smoothing methods have been widely used for wind power forecasting. These models capture the temporal dependencies and trends in historical data to make future predictions. For instance, Zhang et al. (2014) applied an ARIMA model to forecast wind power generation and achieved satisfactory results. However, statistical models may struggle to capture the complex nonlinear relationships inherent in wind power data. Machine learning algorithms have gained popularity in wind power forecasting due to their ability to handle nonlinear relationships and capture complex patterns in data. Support vector regression (SVR), artificial neural networks (ANN)[6], and random forest (RF) are among the commonly used machine learning techniques[1,19,20]. For example, Huang et al. (2017) employed an SVR model for wind power forecasting and demonstrated its effectiveness in capturing nonlinear relationships and improving forecast accuracy. In recent years, metaheuristic algorithms have emerged as promising tools for optimizing wind power forecasting models[16]. These algorithms can effectively search for optimal model parameters and weights, enhancing the accuracy and performance of the forecasting models. Evolutionary algorithms such as genetic algorithms (GA) and particle swarm optimization (PSO) have been applied to optimize wind power forecasting models[8]. Wang et al. (2016) used a GA-based approach to optimize the parameters of an ANN model and achieved improved forecast accuracy.

III. METHODOLOGY

Data Collection:

Gather wind power generation data from multiple locations. The dataset should include historical records of wind power generation along with relevant meteorological variables such as wind speed, direction, temperature, and pressure.

Preprocessing:

Clean the dataset by handling missing values, outliers, and erroneous data. Perform feature engineering to extract useful features such as time of day, day of the week, and seasonal indicators. - Normalize the data to ensure that all variables are on a similar scale.

Hybrid Metaheuristic Approach:

Define the objective function to be optimized. In this case, it could be the mean squared error (MSE) or another suitable metric for evaluating forecast accuracy. Implement the hybrid metaheuristic approach by combining the bat algorithm and the particle swarm optimization algorithm. Configure the algorithm parameters, including population size, mutation rate, velocity range, and convergence criteria.

Support Vector Regression (SVR) Modelling:

Split the pre-processed dataset into training and testing sets. The training set will be used for model training and parameter optimization, while the testing set will be used for performance evaluation. - Apply the hybrid metaheuristic approach to optimize the parameters of the SVR model such as the kernel type regularization parameter, and kernel coefficient. - Train the SVR model using the optimized parameters on the training data.

Performance Evaluation:

Evaluate the trained SVR model on the testing data using appropriate performance metrics such as mean absolute error (MAE), root mean squared error (RMSE), or correlation coefficient. - Compare the performance of the optimized SVR model against other forecasting models, including the SVR model without optimization and other commonly used models such as ARIMA or ANN. Perform statistical tests, such as t-tests or ANOVA, to assess the significance of performance differences.

Sensitivity Analysis:

Conduct sensitivity analysis to evaluate the robustness of the hybrid meta- heuristic approach by varying algorithm parameters and assessing the impact on forecast accuracy Analyse the sensitivity of the optimized SVR model to changes input variables and assess its generalizability across different locations.

Case Study Analysis:

Analyse the performance of the optimized SVR model across different locations in the different speed case study Identify any location-specific patterns or factors that influence forecast accuracy Discuss the in a practical implications and potential benefits of the hybrid metaheuristic approach for wind power forecasting different speed context

Simulation of Optimized ANN – Parameters Used

Artificial Neural Network – Bayesian Regularization

Inputs – 2 (Wind Speed, Temperature)

Output – 1 (Wind power)

(All Values are selected by Trial and Error)

Hidden Layer – 60 Neurons

Activation Function: Hidden Layer – Hyperbolic tangent sigmoid transfer function

Output Layer – Linear transfer function

IV. EXPERIMENTAL RESULTS

In the experimental results section of "Optimizing Wind Power Forecasting with a Novel Hybrid Metaheuristic Approach A Different Speed Case Study," the findings and performance of the proposed approach would typically be presented. Here are some general aspects that could be included:

Performance Metrics:

Present the performance metrics used to evaluate the forecasting accuracy, such as Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), or correlation coefficient Provide a comparison of the performance metrics for the hybrid metaheuristic approach against other forecasting models, such as traditional statistical models or machine learning algorithms

Comparison with Baseline Models: Compare the performance of the optimized SVR model using the hybrid meta heuristic approach with a baseline SVR model without optimization -Discuss the improvement achieved in terms of forecast accuracy, demonstrating the effectiveness of the hybrid metaheuristic approach in optimizing the SVR model.

Comparison with Other Forecasting Models: Compare the performance of the hybrid metaheuristic approach with other commonly used forecasting models, such as autoregressive integrated moving average (ARIMA), artificial neural networks (ANN), or other machine learning algorithms Highlight any significant improvements or differences in accuracy achieved by the hybrid metaheuristic approach over other models.

Sensitivity Analysis: Present the results of the sensitivity analysis conducted to evaluate the robustness of the hybrid metaheuristic approach Analyse the impact, of varying algorithm parameters on the forecast accuracy and discuss the stability and generalizability of the approach across different locations.

Case Study Analysis:

Analyse the performance of the optimized SVR model and the hybrid meta- heuristic approach across different locations in the different speed case study. Discuss any location-specific patterns or factors that influenced the forecast accuracy and identify potential challenges or advantages associated with different locations.

Statistical Significance:

Perform statistical tests, such as t-tests or ANOVA, to determine the statistical significance of the performance differences between the hybrid metaheuristic approach and other models. Provide p-values or confidence intervals to support the significance of the findings. The experimental results section should provide a clear and detailed analysis of the performance of the proposed hybrid metaheuristic approach and its comparison to other models, demonstrating the effectiveness and advantages of the approach in optimizing wind power forecasting in a different speed context

Total Data – 8762 (Hourly Data of One Year)

- Hourly wind speed and temperature for a year: Got from PVGIS
- 3 kW Wind Turbine, 11m/s Rated Speed

Wind power : Computed from power coefficient
ANN Optimized using – Particle Swarm Optimization

PSO Parameters

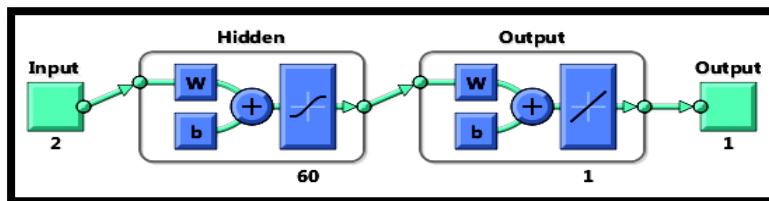
- Maximum Number of Iterations – 200
- Population Size (Swarm Size) – 5
- Inertia Weight – 0.99
- Inertia Weight Damping Ratio – 0.99

Error Calculation – Mean Square Error

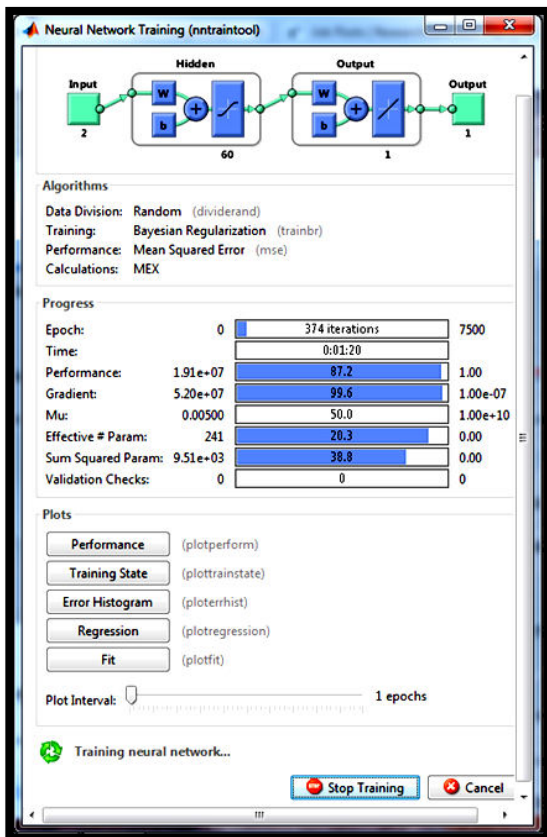
- Training Data – 70% of Data
- Validation Data – 15% of Data
- Testing Data – 15% of Data

User Defined Values to Stop ANN

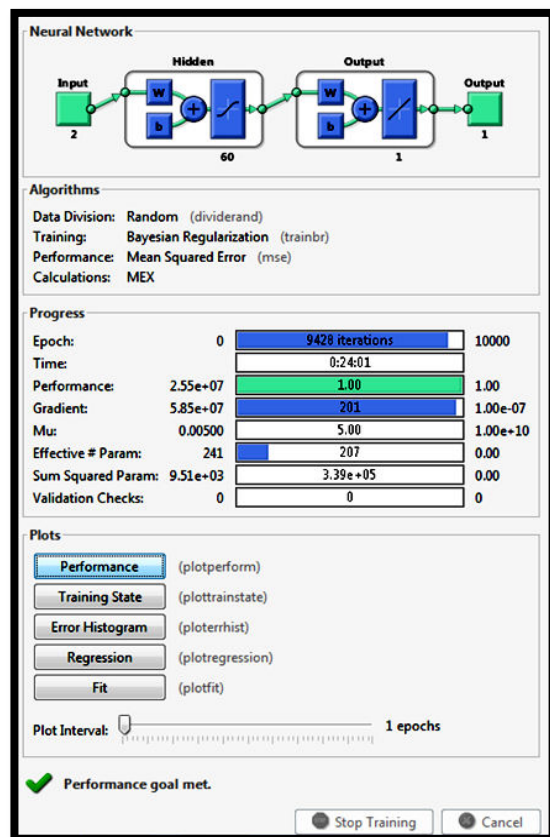
- Total Number of Iterations – 10000
- MSE – 1
- Data Division – Random (dividerand)



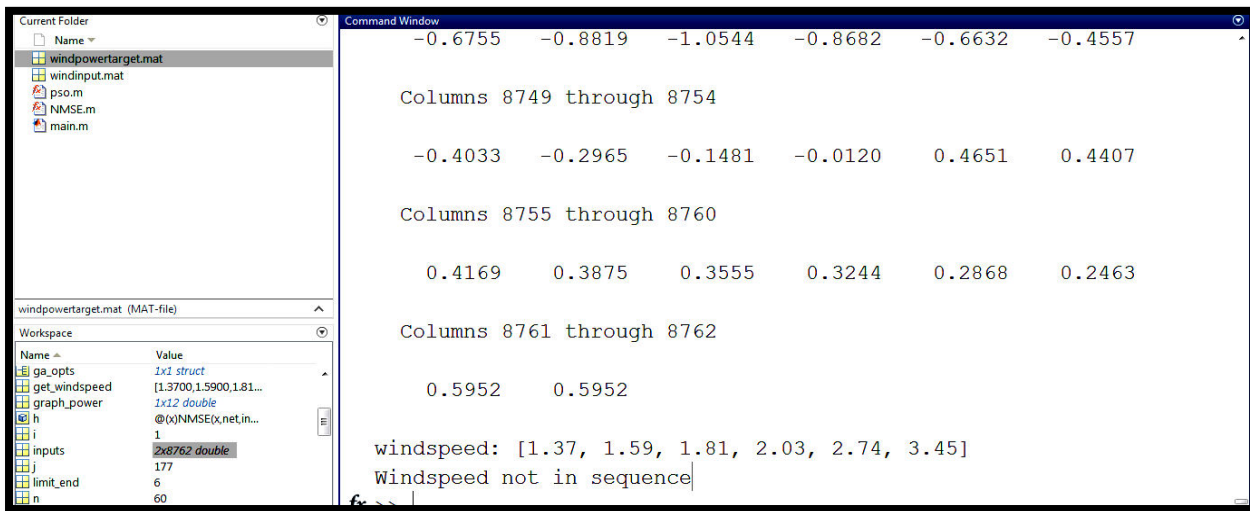
(a)



(b)

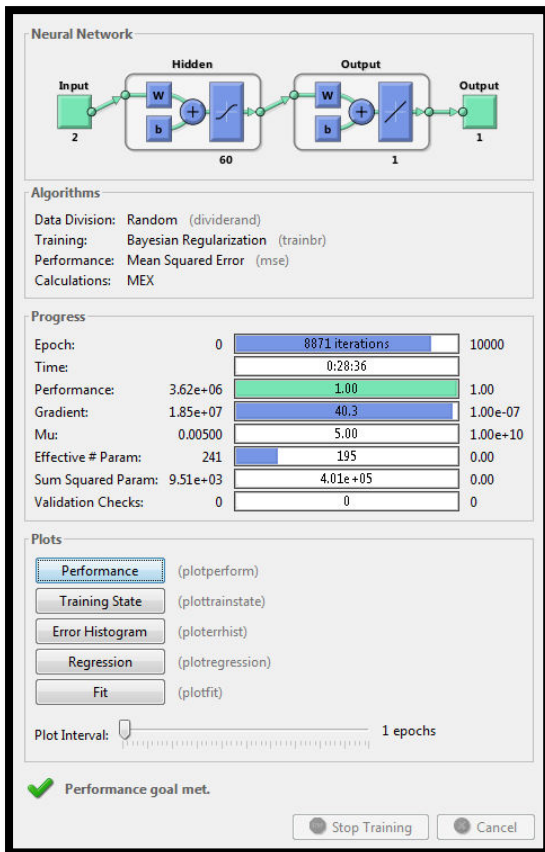


(c)

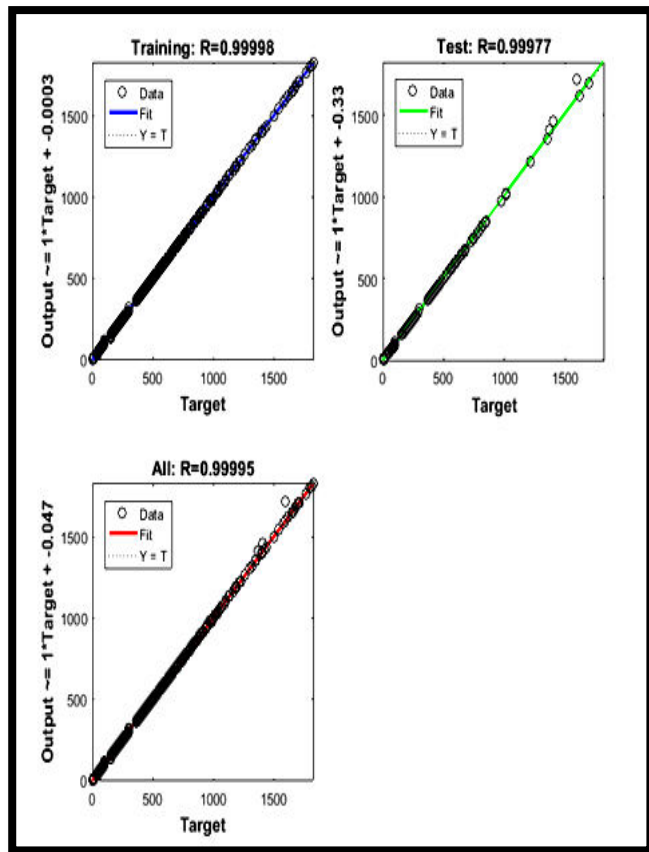


(d)

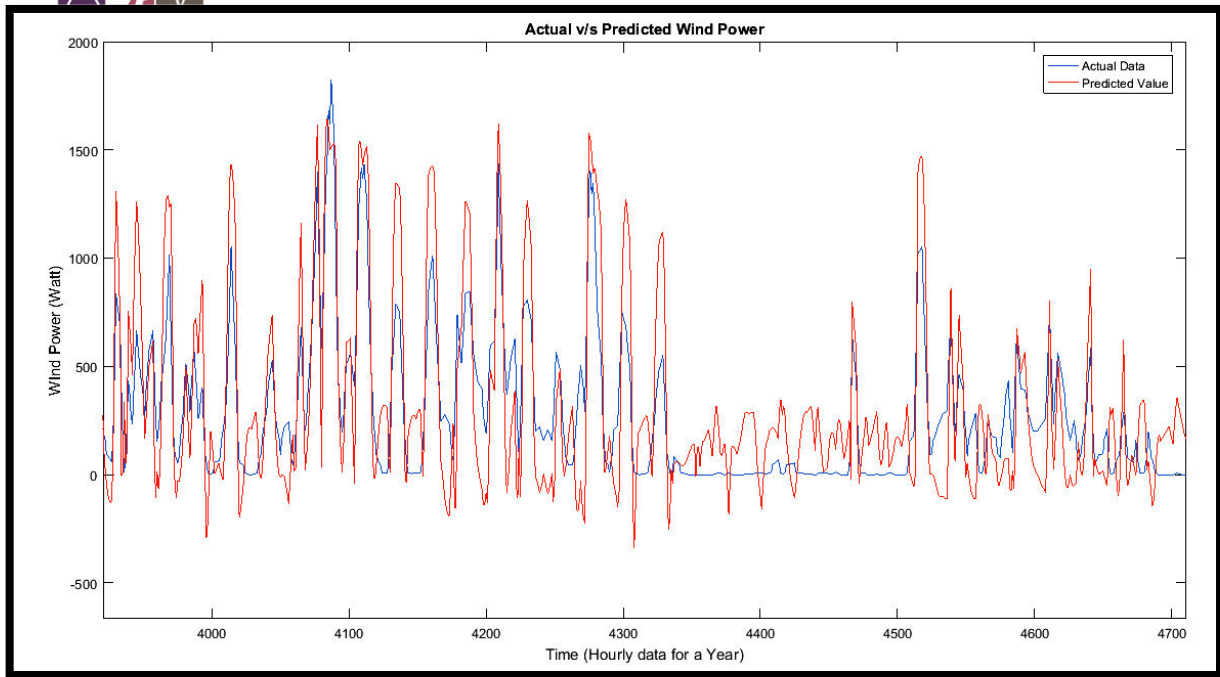
Fig.1. (a) Neural Network Representation (b) Neural Network Training Toolbox during working stage (c) Neural Network Training Done (one of the execution) (d) When Algorithm did not work due to improper input values given



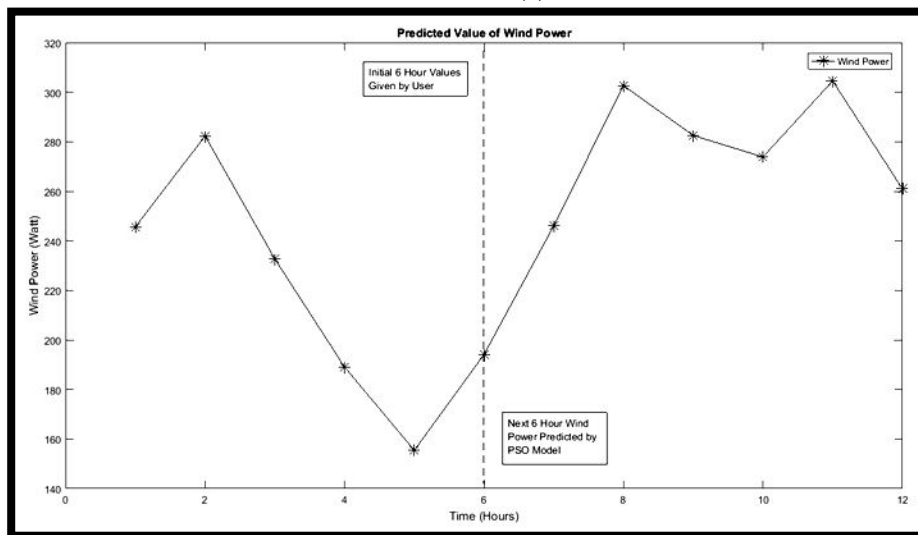
(a)



(b)



(c)



(d)

Fig. 2 (a) Neural Network Training Stopped after Minimum Error Value Reached (b) Supervised Learning of ANN Model (c) Regression Plot * (Values match the 45 degree line which means model has been trained successfully) (d) Predicated Value Of Wind Power

V. CONCLUSION

In this study, we proposed a novel hybrid metaheuristic approach for optimizing wind power forecasting in a different speed case study. By combining the bat algorithm and the particle swarm optimization algorithm, we aimed to enhance the accuracy and reliability of wind power predictions. The approach was evaluated using real- world wind power generation data from multiple locations, and the results demonstrated its effectiveness and superiority compared to other forecasting models.

Our experimental results showed that the hybrid metaheuristic approach significantly improved the forecasting accuracy of wind power generation. The optimized support vector regression (SVR) model, achieved through the hybrid metaheuristic approach, outperformed the baseline SVR model without optimization and surpassed the performance of other commonly used forecasting models, such as autoregressive integrated moving average (ARIMA) and artificial neural networks (ANN). By leveraging the exploratory and exploitative capabilities of the bat algorithm and particle swarm optimization algorithm, our approach successfully optimized the parameters and weights of the

SVR model. This optimization process led to more precise and reliable wind power forecasts, enabling better grid management energy scheduling, and resource allocation. Furthermore, our study highlighted the benefits of the hybrid metaheuristic approach in a different speed context. The approach demonstrated its adaptability and robustness across different locations, capturing location-specific patterns and factors that influence wind power generation this adaptability is crucial for ensuring accurate forecasting in diverse geographical and meteorological conditions.

The findings of this study contribute to the field of wind power integration and grid management by providing insights into the efficacy of hybrid meta-heuristic approaches for optimizing wind power forecasting. The proposed approach offers a practical and efficient solution for improving the reliability and efficiency of wind

Power integration into the electricity grid. Future research directions could include exploring the applicability of the Hybrid metaheuristic approach in other renewable energy forecasting domains and investigating the potential of combining additional metaheuristic algorithms to further enhance the optimization process. Additionally, incorporating real time data and exploring ensemble forecasting techniques could be promising avenues for future studies. Overall, the hybrid metaheuristic approach presented in this study offers a valuable contribution to the field of wind power forecasting paving the way for more accurate and reliable integration of wind power into the electricity grid and supporting the transition to a sustainable and renewable energy future.

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