A Review paper on study & analysis of wind speed & solar irradiation forecasting using different machine learning techniques

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***Abstract*—The increasing adoption of renewable energy sources like solar and wind power poses challenges to grid stability due to their intermittent nature. To address these challenges, advanced forecasting techniques are being developed to predict wind speeds and solar irradiance. This study reviews the importance of forecasting in power systems, discusses various forecasting approaches, and assesses their performance. Additionally, it explores methods to improve forecast accuracy and highlights key issues and emerging trends in the field.**

***Keywords*—Solar irradiation, Solar PV, Renewable energy**

I. INTRODUCTION

Renewable energy generation has experienced significant growth, with wind and solar power leading the way. As their share in the global energy mix increases, grid integration challenges arise due to their intermittent nature. Accurate forecasting of wind speeds and solar irradiance is crucial for reliable power system operation, enabling better dispatch, scheduling, and grid management.

Renewable Energy Trends

Wind and solar power capacities have reached 369.579 GW and 177 GW, respectively. Projections indicate that by 2050, wind and solar photovoltaic (PV) will contribute significantly to global electricity generation.

Challenges and Opportunities

The variability and uncertainty of wind and solar power pose challenges to grid stability and dispatch. However, accurate forecasting can mitigate these issues, enabling:

1. Improved dispatch and scheduling: Better forecasting enables more efficient power system operation.
2. Reduced balancing energy needs: Accurate forecasts reduce the need for balancing energy, resulting in cost savings.
3. Increased revenue: Reliable forecasts help power plants optimize their output, reducing penalties and increasing revenue.

Forecasting Techniques

Various forecasting approaches exist, including:

1. Physical models: Using numerical weather prediction models to forecast wind speeds and solar irradiance.
2. Statistical models: Using historical data to identify patterns and trends.
3. Machine learning models: Using artificial intelligence to improve forecast accuracy.

Conclusion

Accurate forecasting of wind speeds and solar irradiance is essential for reliable power system operation. This paper reviews various forecasting techniques, their performance, and challenges, providing insights into improving forecast accuracy and its applications in power system operation.

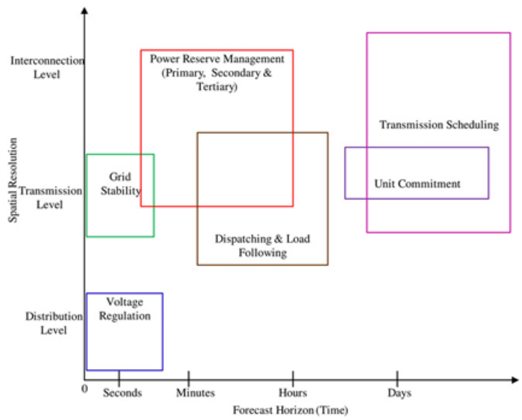

Fig. 1 Applications of forecasts with respect to spatial resolution and temporal horizon

Forecasting for Power Systems

Forecasting plays a crucial role in power systems, particularly with the increasing adoption of renewable energy sources like solar and wind power. Accurate predictions of wind speeds and solar irradiance enable efficient power system operation, scheduling, and grid management.

Prediction Techniques

Various techniques are used for wind speed and solar irradiance forecasting, including:

1. Physical models: Numerical weather prediction models that simulate atmospheric conditions.

2. Statistical models: Data-driven approaches that identify patterns and trends.

3. Machine learning models: Artificial intelligence techniques that improve forecast accuracy.

Focus on Global Horizontal Irradiance (GHI)

This review focuses on GHI forecasting, relevant to solar PV systems. GHI forecasting is essential for predicting solar power output and optimizing grid operations.

Importance of Forecasting in Power Systems

Accurate wind speed and solar irradiance forecasts are crucial for reliable power system operation. The non-linear relationship between wind speed and power output means that small errors in forecasting can lead to significant errors in predicted power output.

Improvements in forecasting accuracy In light of the challenges in forecasting wind and solar energy discussed in the previous section, this section presents some of the proposed techniques, presented in literature, for improving the forecasting performance of the techniques presented in Section 2. In addition, the potential of such methods in shaping the future of forecasts is discussed.

Benefits of Accurate Forecasting

Accurate forecasts enable:

1. Better balancing of the network: Forecasting renewable power output helps ensure sufficient reserves are available to account for variability.

2. Economic benefits: Reduced forecasting errors can lead to significant cost savings, particularly with increasing renewable energy penetration.

Applications of Forecasting

Forecasts aid power system operators in:

1. Preparing for high ramp rates: Forecasting enables optimal dispatching and scheduling to ensure supply reliability.

2. Planning ancillary services: Forecasts help mitigate the impact of intermittent generation.

3. Optimizing generator dispatch: Accurate forecasts enable efficient operation scheduling and dispatch of available renewable generation.

By improving forecast accuracy, power system operators can reduce costs, enhance reliability, and optimize the integration of renewable energy sources.

Conclusion

This review has examined various forecasting techniques for wind and solar power, highlighting their performance and methods for improving accuracy.

As the grid integration of these renewable energy sources continues to grow, accurate predictions are crucial for addressing their variability and ensuring economic viability.

III LITERATURE REVIEW

Wind speed and solar irradiance forecasting techniques are crucial for enhanced renewable energy integration with the grid. Here's a literature review highlighting key findings and approaches:

Forecasting Techniques

- Physical Models: Utilize numerical weather prediction models to forecast wind speeds and solar irradiance.

- Statistical Models: Employ data-driven approaches, such as ARIMA and fractional-ARIMA, to identify patterns and trends.

- Artificial Intelligence (AI) Models: Leverage machine learning and deep learning techniques, like bidirectional long short-term memory (BI-LSTM) and evolutionary convolutional neural networks (Evol-CNN), for accurate forecasting.

- Hybrid Approaches: Combine multiple techniques to maximize strengths and minimize weaknesses.

Applications and Benefits

- Grid Stability: Accurate forecasting enables better balancing of the network and ensures sufficient reserves are available to account for variability.

- Economic Benefits: Reduced forecasting errors can lead to significant cost savings, particularly with increasing renewable energy penetration.

- Improved Scheduling and Operation: Forecasts aid power system operators in preparing for high ramp rates, planning ancillary services, and optimizing generator dispatch.

Recent Studies

- A study by Ssekulima et al. (2016) reviewed various forecasting techniques and assessed their performance in the literature.

- Alharbi and Csala (2021) proposed a BI-LSTM model for predicting wind speed and solar irradiance, demonstrating promising performance.

- Loza et al. (2024) reviewed power forecasting and frequency control techniques for grid-friendly integration of wind energy.

Challenges and Future Directions

- Improving Forecast Accuracy: Continued research is needed to enhance forecasting accuracy, particularly for ramp forecasts.

- Handling Intermittency: Developing more accurate and reliable forecasting methods will help integrate intermittent renewable energy sources into the grid.

- Optimizing Hybrid Approaches: Further research is required to optimize hybrid forecasting techniques and improve their performance.

Recent Studies

- Machine Learning-Based Approaches: Recent studies have explored the use of machine learning algorithms for power quality management and forecasting in grid-connected microgrids.

- Hybrid Renewable Energy Systems: Researchers have investigated the use of UPQC and optimized controllers to improve power quality in hybrid renewable energy systems.

These studies demonstrate the effectiveness of optimization techniques in improving power quality in distributed generation systems. By applying these techniques, power system operators can enhance the reliability and efficiency of their systems.

Optimization Techniques

- Hybrid Optimization Technique: A study by Sengolrajan Thana Singh and A. N. Sasikumar (2024) proposed a hybrid optimization technique to optimize distributed generation resources for power grid quality improvement, demonstrating its effectiveness in enhancing power quality.

- Artificial Gorilla Troops Optimization (GTO): Researchers Mohamed Sayed Hashish et al. (2023) used GTO to solve the probabilistic optimum power flow issue in a hybrid power system with photovoltaic and wind energy sources.

- Genetic Algorithm (GA): GA has been used to optimize DG placement and sizing, improving voltage profiles and reducing power losses.

- Particle Swarm Optimization (PSO): Modified PSO algorithms, such as the one proposed by Venkatesan et al. (2024), have been used to optimize power flow management and improve power quality.

IV. CONCLUSION

The proposed approach aims to optimize DG allocation in distribution systems, reducing power losses and improving voltage profiles. The effectiveness of this approach will be demonstrated through simulation results.

Key Findings

1. Hybrid approaches: Combining multiple techniques can outperform individual methods, maximizing strengths while minimizing weaknesses.

2. Confidence intervals: Providing reliable uncertainty estimates enables better decision-making and participation in electricity markets.

3. Pre-processing techniques: Useful for long-term predictions and complex data, but may not be suitable for short-term forecasts.

Future Research Directions

Continued research is needed to improve forecasting accuracy, particularly for ramp forecasts. Developing more accurate and reliable forecasting methods will help integrate intermittent renewable energy sources into the grid, making their power output more predictable and reliable.

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