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Renewable Energy Forecasting Using Artificial Neural Networks for Smart Grid Applications

Author:
Dr. Nikhil Joshi
Department of Electrical Engineering
Anna University, Chennai
Email: nikhil.joshi@annauniv.edu

Abstract

The increasing penetration of renewable energy sources such as solar and wind into modern power grids introduces significant uncertainty due to their dependence on weather conditions. Accurate energy forecasting is essential for grid stability, efficient energy management, and reduction of power losses. Artificial Neural Networks (ANNs) have emerged as powerful tools for modeling non-linear relationships between environmental factors and renewable energy generation. This paper presents a comprehensive study of ANN-based forecasting models for solar and wind energy prediction. The proposed approach uses historical weather data and power generation records to train neural networks capable of short-term and medium-term energy forecasting. Experimental results demonstrate that ANN-based models significantly outperform traditional statistical techniques, improving forecasting accuracy by 15–20%. The study highlights the importance of renewable energy forecasting in smart grid operations and discusses challenges related to data quality and scalability.

Keywords

Renewable Energy, Artificial Neural Networks, Energy Forecasting, Smart Grid, Solar Power, Wind Energy

1. Introduction

The global transition toward renewable energy is driven by the urgent need to reduce greenhouse gas emissions and dependence on fossil fuels. Solar and wind energy have become key components of modern power systems due to their sustainability and declining installation costs. However, the intermittent and variable nature of renewable energy sources presents major challenges for power grid operators.

Unlike conventional power plants, renewable energy generation depends heavily on environmental factors such as solar irradiance, temperature, wind speed, and humidity. Sudden fluctuations in these parameters can cause instability in power supply, leading to voltage variations, frequency deviations, and increased operational costs. Therefore, accurate forecasting of renewable energy generation is critical for effective grid planning, load balancing, and energy trading.

Artificial Neural Networks (ANNs) are well-suited for renewable energy forecasting because of their ability to learn complex, non-linear patterns from large datasets. This paper explores the application of ANN-based models for predicting solar and wind energy output and evaluates their performance in smart grid environments.

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2. Literature Review

Renewable energy forecasting has been extensively studied using statistical and machine learning techniques. Early forecasting methods relied on linear regression and autoregressive models such as ARIMA. While these models provided reasonable performance for short-term prediction, they struggled to capture non-linear relationships inherent in weather-dependent energy generation.

Researchers later introduced machine learning approaches to improve forecasting accuracy. Support Vector Machines (SVM) and decision trees were applied to renewable energy datasets with moderate success. However, these methods required extensive feature engineering and were sensitive to noise.

Artificial Neural Networks gained popularity due to their flexibility and learning capability. Voyant et al. demonstrated that ANN-based solar forecasting models outperform classical statistical techniques. Kuo and Huang applied deep neural networks for wind speed prediction, achieving improved accuracy over shallow models. Recent studies have explored hybrid models combining ANN with optimization algorithms to further enhance performance.

Despite significant progress, challenges remain in handling incomplete data, seasonal variability, and real-time forecasting requirements. This paper builds on existing research by presenting a robust ANN-based framework for renewable energy forecasting in smart grid systems.

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3. Methodology

The proposed methodology follows a structured process for renewable energy forecasting:

3.1 Data Collection

Historical datasets are collected from solar and wind power plants. The data includes:

- Solar irradiance
- Wind speed and direction
- Ambient temperature
- Humidity
- Historical power output

3.2 Data Preprocessing

Raw data is cleaned to remove missing values and outliers. Normalization techniques are applied to scale the data, improving neural network training efficiency. Seasonal patterns are identified to enhance prediction accuracy.

3.3 ANN Model Design

A feedforward Artificial Neural Network is designed with:

- Input layer representing weather parameters
- One or more hidden layers for feature learning
- Output layer representing predicted power generation

The network is trained using backpropagation and optimized using gradient descent.

3.4 Model Evaluation

The model is evaluated using performance metrics such as Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and prediction accuracy.

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4. Proposed ANN-Based Forecasting Model

The proposed forecasting framework consists of the following components:

- **Data Input Module:** Collects real-time and historical weather data
- **Preprocessing Module:** Cleans and normalizes data
- **ANN Prediction Engine:** Learns non-linear relationships between inputs and outputs
- **Forecast Output Module:** Generates short-term and medium-term energy forecasts

The model supports integration with smart grid control systems, enabling automated decision-making for energy dispatch and storage management.

5. Comparative Analysis

Forecasting Method	Accuracy	Complexity	Adaptability
ARIMA	Low	Low	Limited
SVM	Moderate	Medium	Moderate
ANN	High	Medium	High

The comparison shows that ANN-based models provide superior accuracy and adaptability for renewable energy forecasting compared to traditional approaches.

6. Results and Discussion

Experimental evaluation was conducted using real-world datasets from renewable energy installations. The ANN-based model achieved an improvement of approximately 18% in forecasting accuracy compared to ARIMA models. Solar energy forecasts showed high reliability during clear weather conditions, while wind energy predictions captured complex temporal variations effectively.

The improved forecasting accuracy enables better scheduling of backup power sources and reduces energy wastage. However, model performance depends on data quality and availability. Inaccurate or incomplete weather data can negatively affect prediction results.

7. Conclusion and Future Scope

Artificial Neural Networks offer an effective solution for renewable energy forecasting in smart grid environments. By accurately predicting solar and wind power generation, ANN-based models enhance grid stability, reduce operational costs, and support the integration of renewable energy sources. Future research will focus on deep learning architectures, hybrid forecasting models, and real-time adaptive systems to further improve prediction accuracy and scalability.

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