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A Literature Review on Solar Energy Output Prediction using Various Machine Learning Techniques

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Abstract: *This literature survey explores various machine learning and deep learning models used for solar energy forecasting. A total of 15 papers published between 2020-2023 were reviewed. The objective of the survey was to identify the advancements made in the field of solar energy forecasting using machine learning and deep learning techniques. The survey found that most studies focused on using artificial neural networks (ANN) and deep learning models such as long short-term memory (LSTM) and convolutional neural networks (CNN) for solar energy forecasting. Several studies used ensemble models, such as stacking and bagging, to improve the accuracy of solar energy forecasts. Other studies used feature selection techniques and autoencoders to reduce the dimensionality of data and improve the accuracy of predictions. The survey also found that the availability of data is crucial for accurate solar energy forecasting. Many studies used data from meteorological agencies, such as NASA, NOAA, and ECMWF, along with satellite images and sky cameras to generate accurate forecasts. The use of IoT devices and sensors was also explored in some studies to obtain real-time data for improved forecasting. Overall, the literature survey found that machine learning and deep learning techniques have shown great promise in improving the accuracy of solar energy forecasting. The use of ensemble models, feature selection techniques, and autoencoders has improved the accuracy of forecasts. However, the availability of data is crucial for accurate forecasting. The use of IoT devices and sensors can provide real-time data that can be used for accurate forecasting.*

Keywords: Slime mould algorithm, LGBM, KNN, Random Forest, DNN, Photovoltaic

I. INTRODUCTION

The renewable energy revolution is without a doubt one of the most important projects for environmental and social benefits. Sunlight is one of the renewable resources with the greatest potential to replace fossil fuels. Due to its abundance, accessibility, and sustainability, solar energy has become a competitive alternative to conventional energy sources. Forecast data is necessary for the optimal use of energy, its planning, the balance, and stability of the solar energy system. The method used in this study achieves greater forecast accuracy compared to current quality standards. The path and energy of the sun can be calculated using physical laws, but it is still very difficult to predict how solar energy will develop and be produced using physical simulation and artificial intelligence. The primary reason for this is that several variables, like the position of the sun, the climate, the properties of photovoltaic panels, and others, have an impact on the amount of solar energy that is generated. The precision of the solar forecast is crucial for maintaining the balance, stability, and planning of the power grid's energy production.

Renewable energy sources can be categorised into two main categories from the standpoint of grid operations: dispatchable, which includes geothermal, solar with storage, biomass, and hydro; and non-dispatchable, which primarily depends on climatic and oceanic conditions and is uncontrollable. This category includes energy sources like solar cells, windmills, and ocean currents. Power system operating plans are built on precise forecasts of the conditions that will occur throughout a range of anticipated time periods, such as days, hours, or minutes in the future. The prediction of solar energy output using machine learning methods is the main topic of this study. For the purpose of increasing the precision of solar energy production prediction, we suggest a hybrid fusion model that fuses the advantages of various machine learning algorithms. To forecast solar energy output, the model considers a variety of input factors, including weather information, the time of day, and the location. The implementation of photovoltaic energy generation and the forecasting of hourly solar radiation are both greatly facilitated by this approach.

SOLAR ENERGY OUTPUT PREDICTION – NEED FOR THE STUDY

The need for the study arises from the increasing demand for solar energy as a renewable energy source. Accurate prediction of solar radiation is crucial for efficient energy generation and management. However, prediction accuracy is influenced by various factors. Machine learning models have been widely used to predict solar radiation, but selecting the most relevant features for accurate prediction remains a challenge. Predicting the hourly basis of solar energy radiation production for the peak hour of solar light radiation from ten in the morning to three in the evening Most of the research articles cover only the solar radiation on a monthly, daily, and particular period of days basis to predict the solar power energy. Most of the researchers in this area of renewable source management don't cover the hourly basis of solar energy output prediction. So, in this study, we are covered on an hourly basis for better solar power energy management and optimization. The main objective of the study is to develop a model that accurately predicts the amount of solar energy that can be generated from a PV system, based on various input factors such as weather conditions, location, and system specifications. The model should be reliable and accurate, with a low margin of error. Evaluate the model's performance to compare and evaluate the performance of various machine learning models, including KNN, LGBM, Random Forest, and DNN, for hourly solar radiation prediction. To evaluate the impact of feature selection using SMA on the prediction accuracy of the machine learning models and to develop a hybrid fusion model that integrates the slime mould algorithm and machine learning models for accurate solar radiation prediction.

III. LITERATURE REVIEW

Mishra, D. P., Jena, S., Senapati, R., Panigrahi, A., & Salkuti, S. R. (2023), The objective of this study is to forecast global solar radiation using an ensemble learning approach that combines the predictions of several machine learning models. The authors aim to develop an accurate and reliable solar radiation forecasting model that can be used for renewable energy planning and management. The study proposes a novel approach that incorporates multiple machine learning models, including artificial neural networks, support vector machines, and random forests, to achieve better accuracy and reliability than single-model approaches. The proposed approach is tested and validated using real-world data, demonstrating its effectiveness in accurately predicting global solar radiation. [1]

Deo, R. C., Ahmed, A. M., Casillas-Pérez, D., Pourmousavi, S. A., Segal, G., Yu, Y., & Salcedo-Sanz, S. (2023),To develop a kernel ridge regression (KRR) based approach for correcting cloud cover bias in numerical weather prediction models, which can improve the accuracy of solar energy monitoring and forecasting systems. The proposed approach uses KRR with various meteorological input variables and cloud cover as the output variable, and it is tested on a case study site in Australia. The study aims to demonstrate the effectiveness of KRR in correcting the cloud cover bias and providing accurate solar radiation forecasts, which can support the integration of solar energy into the grid. [2]

You, L., & Zhu, M. (2023),Developing a digital twin simulation and deep learning framework for predicting solar energy market load using trade-by-trade data. The paper proposes a novel approach to construct a digital twin simulation model that mirrors the real-world solar energy market and integrates it with a deep learning framework to generate accurate predictions of the market load. The framework is trained and tested on historical trade-by-trade data, and the performance of the model is evaluated and compared with traditional machine learning methods.[3]

Krishnan, N., Kumar, K. R., & Inda, C. S. (2023),The objective of this paper is to critically review the literature on the impact of solar radiation forecasting on the utilization of solar energy. The authors aim to identify the key factors that influence the accuracy of solar radiation forecasting and how it impacts the utilization of solar energy. The paper also examines the various techniques used for solar radiation forecasting and evaluates their effectiveness. The review provides insights into the current state of research in the field and highlights the gaps in knowledge that need to be addressed to improve the utilization of solar energy. [4]

Immanual, R., Kannan, K., Chokkalingam, B., Priyadharshini, B., Sathya, J., Sudharsan, S., & Nath, E. R. (2023), This study aimed to develop an Artificial Neural Network (ANN) model for predicting the performance of solar stills, which are used for desalination and water purification. The ANN model aims to predict the productivity and efficiency of the solar still, which are affected by various factors such as solar radiation, ambient temperature, wind speed, and water depth. The study proposes an ANN model that can accurately predict the performance of solar stills, which can be used for the design and optimization of solar stills for various applications in water desalination and purification.[5]

Rahimi, N., Park, S., Choi, W., Oh, B., Kim, S., Cho, Y. H., ... & Lee, D. (2023), In this article the objective is to provide a comprehensive review of ensemble solar power forecasting algorithms. The study aims to evaluate the performance of different ensemble methods in improving the accuracy of solar power forecasting. The article discusses various ensemble methods used in solar power forecasting, including simple averaging, weighted averaging, bagging, boosting, and stacking. The review also discusses the advantages and disadvantages of each method and provides insights into the factors that affect the accuracy of ensemble forecasting models. The article concludes by highlighting the importance of ensemble methods in improving the accuracy of solar power forecasting. [6]

Kong, X., Du, X., Xu, Z., & Xue, G. (2023), Developing a predictive model for solar radiation that can be used for space heating with thermal storage systems. The authors propose a novel method based on a temporal convolutional network-attention model, which incorporates both temporal and spatial information from multiple weather variables. The model aims to improve the accuracy and reliability of solar radiation prediction, and ultimately optimize the performance of the thermal storage system. The study also evaluates the effectiveness of the proposed model and compares it with other commonly used machine learning algorithms.[7]

Nie, Y., Li, X., Scott, A., Sun, Y., Venugopal, V., & Brandt, A. (2023),The objective of this paper is to introduce a new dataset called SKIPP'D (SKy Images and Photovoltaic Power Generation Dataset), which includes high-resolution sky images and photovoltaic (PV) power generation data. The paper aims to demonstrate the potential of this dataset in improving short-term solar forecasting accuracy. Specifically, the paper discusses the collection and pre-processing of the dataset and presents a case study demonstrating the usefulness of SKIPP'D for solar power forecasting using machine learning algorithms. The ultimate goal of the paper is to contribute to the development of accurate and efficient solar power forecasting methods. [8]

Bezerra Menezes Leite, H., & Zareipour, H. (2023),This article aims to develop an accurate forecasting model for small behind-the-meter solar sites that can predict energy production six days ahead. The authors aim to compare the performance of different forecasting models and evaluate the impact of weather forecast accuracy, solar site characteristics, and historical data availability on the accuracy of the energy production forecast. The study focuses on small solar sites that are connected to the distribution grid and have a capacity of less than 500 kW, which are becoming increasingly popular due to their potential to reduce greenhouse gas emissions and support distributed generation. [9]

Ghimire, S., Deo, R. C., Casillas-Pérez, D., Salcedo-Sanz, S., Sharma, E., & Ali, M. (2022),proposed a novel deep learning CNN-LSTM-MLP hybrid fusion model for feature optimization and accurate prediction of daily solar radiation. The proposed model combines the strengths of convolutional neural networks (CNNs), long short-term memory (LSTM) networks, and multilayer perceptron (MLP) networks for effective feature extraction and modeling of the complex non-linear relationships between the input variables and solar radiation. The performance of the proposed model is evaluated and compared with other state-of-the-art models using real-world solar radiation data, demonstrating its superiority in terms of prediction accuracy and robustness. [10]

Patel, D., Patel, S., Patel, P., & Shah, M. (2022),The objective of the study is to develop a comprehensive and systematic approach for the estimation of solar radiation and solar energy using artificial neural network (ANN) and fuzzy logic concept. The study aims to optimize the ANN architecture using various training algorithms and activation functions to improve the accuracy of solar radiation and energy estimation. Additionally, the study aims to develop a fuzzy logic-based inference system to enhance the estimation performance by integrating expert knowledge and linguistic variables. The proposed approach aims to provide an effective tool for solar radiation and energy estimation for practical applications. [11]

Ghimire, S., Deo, R. C., Wang, H., Al-Musaylh, M. S., Casillas-Pérez, D., & Salcedo-Sanz, S. (2022), Develop a stacked LSTM sequence-to-sequence autoencoder with feature selection for accurate daily solar radiation prediction. The study aims to review and improve upon existing models for predicting solar radiation by incorporating a sequence-to-sequence autoencoder with a stacked LSTM model, which can capture nonlinear relationships and temporal dependencies in the data. Additionally, the study employs feature selection to identify the most relevant input variables and reduce the dimensionality of the problem. The proposed model is evaluated and compared with existing models to demonstrate its effectiveness in solar radiation prediction. [12]

Khan, W., Walker, S., & Zeiler, W. (2022),In this study, they propose an improved deep learning-based ensemble stacking approach for the accurate forecast of solar photovoltaic (PV) energy generation. The study aims to develop a model that can handle the nonlinear and complex relationships between the variables affecting solar PV energy generation, by utilizing the strengths of different deep learning algorithms in an ensemble stacking framework. The study seeks to evaluate the performance of the proposed model and compare it with existing forecasting models, to demonstrate its superiority in terms of accuracy and robustness. [13]

Shams, M. H., Niaz, H., Hashemi, B., Liu, J. J., Siano, P., & Anvari-Moghaddam, A. (2021),The author proposed a novel artificial intelligence-based approach for predicting and analyzing the oversupply of wind and solar energy in power systems. The proposed approach utilizes machine learning algorithms to forecast renewable energy generation and demand, and to detect oversupply events. The approach is evaluated using real-world data from the Irish power system, and the results demonstrate its ability to accurately predict oversupply events, as well as its potential to support the integration of large amounts of renewable energy into power systems. [14]

Sahu, R. K., Shaw, B., & Nayak, J. R. (2021),In this article, The author proposed a system that optimize Extreme Learning Machine (ELM) is employed to forecast real-time SPG of Chhattisgarh state of India by conceding weather conditions for prediction. The study aims to improve the accuracy of solar power forecasting by incorporating weather variables such as temperature, humidity, and wind speed, along with historical solar irradiance data. The proposed model is expected to aid decision-making in power system operations, energy trading, and renewable energy integration planning in Chhattisgarh state. [15]

Alkhayat, G., & Mehmood, R. (2021), The objective of this article is to provide a comprehensive review and taxonomy of wind and solar energy forecasting methods based on deep learning. The authors aim to summarize the existing literature on deep learning-based forecasting methods for wind and solar energy, identify the strengths and weaknesses of different approaches, and provide insights into future research directions. The review covers a range of deep learning techniques including convolutional neural networks, long short-term memory networks, and hybrid models. The article also discusses various applications of deep learning-based forecasting methods in renewable energy systems.[16]

Jebli, I., Belouadha, F. Z., Kabbaj, M. I., & Tilioua, A. (2021),In this paper, The author investigate and evaluate the performance of deep learning models for predicting solar energy production. The study aims to compare the effectiveness of different deep learning algorithms, including Convolutional Neural Network (CNN), Long Short-Term Memory (LSTM), and Hybrid models, in forecasting solar energy production based on various input variables, such as solar irradiance and temperature. The authors aim to provide insights into the applicability and limitations of deep learning models for solar energy prediction and suggest potential areas of improvement for future research.[17]

Yamin, N., & Bhat, G. (2021, July), The objective of this paper is to propose an online solar energy prediction algorithm for energy-harvesting Internet of Things (IoT) devices. The algorithm aims to provide accurate and timely predictions of solar energy availability to enable efficient energy management and improve the performance of energy harvesting IoT devices. The paper presents a machine learning-based approach that utilizes historical solar energy data and real-time weather data to predict solar energy availability for the next time interval. The proposed algorithm is evaluated using real-world data, and the results demonstrate its effectiveness in accurately predicting solar energy availability.[18]

Gupta, A., Bansal, A., & Roy, K. (2021, May). Developing a solar energy prediction model using the decision tree regressor algorithm. The study aims to analyse the performance of the decision tree model in predicting solar energy generation and compare it with other traditional machine learning algorithms such as linear regression, random forest, and support vector regression. The study also aims to identify the most important features that contribute to solar energy prediction and to evaluate the model's accuracy using various performance metrics such as mean absolute error, mean squared error, and coefficient of determination.[19]

Li, S., Chen, H., Wang, M., Heidari, A. A., & Mirjalili, S. (2020), The objective of this paper is to introduce the Slime Mould Algorithm (SMA), a new optimization method inspired by the foraging behaviour of slime molds, which has shown potential for solving complex optimization problems. The authors present the basic principles of the SMA and its key components, including the initial slime mould's distribution, environmental conditions, and the adaptation of the slime mould to changing conditions. They also demonstrate the effectiveness of the SMA on a range of benchmark problems and compare its performance with other well-known optimization algorithms, including Genetic Algorithm, Particle Swarm Optimization, and Ant Colony Optimization. [20]

Obiora, C. N., Ali, A., & Hassan, A. N. (2020, October),Developing and compare machine learning models for predicting hourly solar irradiance. The authors aim to evaluate the performance of various regression algorithms, including Artificial Neural Networks (ANN), Support Vector Regression (SVR), and Random Forest Regression (RFR), in accurately forecasting solar irradiance. The study also aims to identify the most suitable input features that can improve the prediction accuracy of the models. The ultimate goal of the research is to provide accurate and reliable solar irradiance forecasts, which are crucial for efficient and effective solar energy utilization.[21]

JEBLI, I., BELOUADHA, F. Z., & KABBAJ, M. I. (2020, March), The objective of this paper is to study the application of machine learning techniques in forecasting solar energy output. The authors explore the performance of various machine learning algorithms, including linear regression, decision tree, random forest, and neural networks, in predicting solar radiation levels. The study also examines the impact of various weather parameters, such as temperature, humidity, and cloud cover, on solar energy output prediction. The aim of this research is to contribute to the development of accurate and reliable solar energy forecasting models, which can aid in the integration of solar power into the energy grid.[22]

Erduman, A. (2020) The objective of this study was to develop a smart short-term solar power output prediction system using an artificial neural network (ANN) to improve the accuracy of solar power output prediction. The study aimed to use the ANN model to predict the solar power output of a photovoltaic (PV) system over a short period of time (15 minutes) and to compare the results with those of traditional methods such as persistence and linear regression. The ultimate goal was to improve the efficiency and reliability of solar power generation by accurately predicting solar power output.[23]

Gangwani, P., Soni, J., Upadhyay, H., & Joshi, S. (2020),Proposed a deep learning approach for modelling geothermal energy prediction. The study aims to develop an accurate model for geothermal energy prediction, which can help in the efficient utilization of geothermal energy resources. The proposed approach involves the use of long short-term memory (LSTM) networks for predicting the geothermal energy output. The study aims to evaluate the performance of the proposed model and compare it with other existing methods for geothermal energy prediction.[24]

Zhang, R., Feng, M., Zhang, W., Lu, S., & Wang, F. (2018, November),In this article, the author proposed a deep learning approach for accurately forecasting solar energy production by leveraging spatio-temporal patterns in weather and solar irradiance data. The proposed model integrates convolutional neural networks (CNNs) and long short-term memory (LSTM) networks to effectively capture both spatial and temporal dependencies in the data and utilizes a residual learning architecture to improve prediction accuracy. The authors evaluate the performance of the proposed model on real-world solar energy datasets and demonstrate its superiority over existing baseline methods.[25]

IV. CONCLUSION

From the literature survey, it is evident that a wide range of forecasting models have been developed for predicting solar energy production. Artificial neural networks (ANNs) and support vector regression (SVR) are the most commonly used techniques in solar energy forecasting. In addition, deep learning models, such as convolutional neural networks (CNNs), long short-term memory (LSTM) networks, and stacked autoencoders (SAEs) have been found to outperform traditional models in many cases. Many studies have focused on developing ensemble forecasting models to improve the accuracy of solar energy predictions. Such models integrate multiple forecasting methods to provide more accurate and reliable results. Stacking methods and hybrid models have been used to combine the strengths of different models and reduce the weaknesses of each method. Some studies have also explored the use of feature selection techniques to identify the most significant predictors for solar energy forecasting. This approach helps to reduce model complexity and improve the accuracy of the predictions.

Finally, it is worth noting that there are still challenges and limitations associated with solar energy forecasting. For instance, the variability and uncertainty of weather patterns can impact the accuracy of solar energy forecasts. The quality and quantity of data used for model training can also affect the performance of the forecasting models. In conclusion, the literature survey highlights the significant advancements made in solar energy forecasting using machine learning and deep learning models. However, there is still a need for further research to address the challenges and limitations associated with solar energy forecasting. Future studies can focus on exploring new methods and techniques to improve the accuracy and reliability of solar energy predictions, making renewable energy sources a more attractive option for meeting global energy demand.

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