A systematic review to improved sustainability in forecasting of renewable sources of energy with solar and wind

Amol Arun Kolhe[1,] Dr. Rahul Kumar Budania[2,] Dr. Pravinkumar Rajkumar Badadapure[3]
[1]Research Scholar, Shri Jagdishprasad Jhabarmal Tibrewala University, Vidyanagari, Rajasthan, Electrical Engineering

[2]Professor, Shri Jagdishprasad Jhabarmal Tibrewala University, Vidyanagari, Rajasthan, Electrical Engineering
[3]Professor, Shri Jagdishprasad Jhabarmal Tibrewala University, Vidyanagari, Rajasthan, Electrical Engineering

Abstract— **Sustainability of the earth depends on renewable energy. Forecasting the output of renewable energy has a big impact on how we operate and manage our power networks. To guarantee grid dependability and permanence and to lower the danger and expense of the energy market and systems, accurate forecasting of renewable energy output is essential. Researchers have been drawn to this topic by deep learning's recent success in a variety of applications, and its bright future is shown in the variety of proposed approaches and the rising number of publications. This paper reviews deep learning-based solar and wind energy forecasting research that has been published over the past five years, covering in-depth topics such as the data and datasets used in the reviewed works, data pre-processing techniques, deterministic and probabilistic techniques, and evaluation and comparison methods. To facilitate methodological comparisons, the key traits of all the reviewed publications are compiled in tabular form. The field's existing difficulties and potential areas for future research are described. According to trends, recurrent neural network models, including those with long short-term memories and gated recurrent units, are second most frequently utilized in this sector behind hybrid forecasting models, with convolutional neural networks coming in third. We also observe an increase in interest in probabilistic and multistep forecasting techniques. Using the important learnings from this thorough study, we also create a comprehensive taxonomy of the research, which will, in our opinion, be essential for comprehending the cutting-edge and promoting innovation in this area.**

Index Terms—**Sustainability, energy, networks, datasets, techniques, models, innovation**

I. INTRODUCTION

Numerous academics have turned their attention to this area as a result of the growing global interest in renewable energy sources and the growth of integrating such sources into the electrical grid [1-3]. Load forecasting, forecasting the output of renewable energy sources, energy pricing, detecting power quality disruptions, and defect detection on power systems and equipment are all common applications of smart energy systems. Forecasting the output of renewable energy sources, particularly wind and solar energy, has received a lot of attention recently due to its enormous influence on decisions about the operation and management of power networks. To assure grid dependability, permanence, and reduce risk, accurate forecasting of renewable energy output is essential. Writing partner. Deep learning and renewable energy are two of the most important and promising technologies for the future. This paper reviews recent deep learning-based research on solar and wind energy forecasting, covering the data and datasets used in the reviewed works, data pre-processing techniques, deterministic and probabilistic techniques, as well as evaluation and comparison techniques. To allow for methodological comparisons, the key traits of all the reviewed publications are compiled in tabular form. There is a suggested general taxonomy for the research. Hybrid models are the most popular architectures, followed by recurrent neural network models, such as the Long Short-Term Memory model and Gated Recurrent Unit, and then Convolutional Neural Networks, which come in third. Data decomposition techniques and feature selection approaches make up the majority of strategies used in combination with deep learning models. The results of all the experiments in the included studies show that deep learning-based forecasting models consistently outperform other machine learning models and statistical techniques in terms of accuracy and generalization ability, especially when they are combined with other algorithms to create hybrid models. Without comprehensive testing using datasets from various climates and topographies that contain information on all seasons and weather conditions, it is impossible to pinpoint the forecaster that performs the best.

II. LITERATURE REVIEW

Afshin et. al. (2023) states that solar energy is a widely accessible, clean, and sustainable energy source. Solar power harvesting in order to generate electricity on smart grids is essential in light of the present global energy crisis. However, the highly variable nature of solar radiation poses unique challenges for accurately predicting solar photovoltaic (PV) power generation. Factors such as cloud cover, atmospheric conditions, and seasonal variations significantly impact the amount of solar energy available for conversion into electricity. In addition, RFR and LSTM demonstrate their capability to capture the intricate patterns and complex relationships inherent in solar power generation data. The developed machine learning models can aid solar PV investors in streamlining their processes and improving their planning for the production of solar energy. [1]

Louis et. al. (2022) states that reducing carbon emissions and electricity costs in industry is a major challenge to ensure competitiveness and compliance with new climate policies. Photovoltaic power offers a promising solution but also brings considerable uncertainties and risks that may endanger the continuity and quality of supply. From an operational point of view, large-scale integration of solar power could result in unmet demand, electrical instabilities and equipment damage. The performance and lifetime of conventional fossil equipment are likely to be altered by repeated transient operations, making it necessary to adopt specific modelling tools.[2]

Moon-Soo et. al. (2022) mentioned that heavy snowfall is a natural disaster that causes extensive damage in South Korea. Therefore, it is crucial to predict snowfall occurrence and establish countermeasures to reduce the damage caused by heavy snowfall. In this study, the meteorological and geographic data of the past 30 years were collected, and four machine learning algorithms were used: multiple linear regression (MLR), support vector regression (SVR), random forest regressor (RFR), and eXtreme gradient boosting (XGB). Subsequently, the performances of the machine learning algorithms were compared. Machine-learning algorithms were selected as regression models to predict heavy snowfall. Additionally, grid search and five-fold cross-validation techniques were used to improve learning performance. Model performance was evaluated by comparing the observed and predicted data. It was observed that the RFR model accurately predicted the occurrence of snowfall (R2=0.64) compared with other models with various statistical criteria. [3]

Altaf et. al. (2022) states that for efficient energy distribution, microgrids (MG) provide significant assistance to main grids and act as a bridge between the power generation and consumption. Renewable energy generation resources, particularly photovoltaics (PVs), are considered as a clean source of energy but are highly complex, volatile, and intermittent in nature making their forecasting challenging us a reliable, optimized, and a robust forecasting method deployed at MG objectifies these challenges by providing accurate renewable energy production forecasting and establishing a precise power generation and consumption matching at MG.
[4]

Zhigang et. al. (2022) states that the prediction of time series is of great significance for rational planning and risk prevention. However, time series data in various natural and artificial systems are nonstationary and complex, which makes them difficult to predict. An improved deep prediction method is proposed herein based on the dual variational mode decomposition of a nonstationary time series. First, criteria were determined based on information entropy and frequency statistics to determine the quantity of components in the variational mode decomposition, including the number of subsequences and the conditions for dual decomposition. Second, a deep prediction model was built for the subsequences obtained after the dual decomposition. Third, a general framework was proposed to integrate the data decomposition and deep prediction models. [5]

Haoyin et. al. (2022) states that the physical prediction method refers to a technology that excavates the factors related to PV power generation from the principle and then creates a physical model. Specifically, physical method modelling is based on numerical weather prediction (NWP) by utilizing atmospheric physical data including wind speed, temperature, rainfall, humidity, length of day, and cloud image via a total sky imager or satellite. Besides, it can be further classified as a simple physical model method and a complex physical model method. A simple physical model needs power system parameters, weather data, satellite observations, and so on.[6]

III. PROSPOSED SYSTEM

Since its very difficult to identify the exact issues associated for forecasting of solar and wind energy due to lack of information in a systematic way pr may be due to less parameter's comparison with certain deep learning techniques. This emerges the urgent need for a study of deep learning-based forecasting studies for renewable energy sources. This paper reviews recent deep learning-based research on solar and wind energy forecasting. It discusses in detail the data and datasets used in the reviewed works, data pre-processing techniques, deterministic and probabilistic techniques, as well as evaluation and comparison techniques. It took a lot of work to compile a comprehensive list of all the examined works' essential traits and present them in tabular formats. the most recent developments in the field and has also enabled us to put up a comprehensive taxonomy for deep learning-based research on solar and wind energy forecasting. Although there was no such comprehensive taxonomy of deep learning-based research on solar and wind energy forecasting, we believe that it will be crucial for identifying and comparing works on the subject, eventually fostering innovation in this area. Our suggested approaches serve to clarify the fact that the current methods for predicting the amount of wind and solar energy are insufficient to determine the outcome. So, by comparing more than 2 techniques helps to identify the flaws in the previous system or may increase the accuracy of forecasting.

IV. OBJECTIVES OF PROPOSED SYSTEM

Following are the objectives which will be achieved:

- To forecast the renewable energy in market data by using machine learning regression algorithms
- To compare various algorithm and techniques by the use of relevant dataset
- To process linear regression and ridge regression to provide better sustainability solution
- To evaluate the performance such as mae,mse,rmse and mape

V. NEED OF THE STUDY

Due to the variable nature of weather, there will always be instability of the energy output from solar and wind energies. Thus, their output prediction is difficult and requires advanced methods. The techniques used for this task can be classified into four categories: physical methods, statistical models, artificial intelligence techniques, and their hybrid methods. Physical methods or Numerical Weather Prediction (NWP) models are mathematical models that simulate the atmospheric dynamics according to physical and mechanical principles. Since they depend on computer simulation, they require extensive computer resources and thus are used for long term forecasting horizon. This extensive review provides key insights into the state-of-the-art on the topic and has also allowed us to propose a broad taxonomy of deep learning-based solar and wind energy forecasting research. The forecast horizon includes four categories: ultra-short-term, short-term, medium-term, and long-term. The forecasting approach could be deterministic or probabilistic targeting the next time step or multi-steps. The data used for forecasting might be spatial, time series, or sky images. It could be the historical values of the wind speed or wind power for wind energy forecasting and solar power or solar irradiance for solar energy forecasting. This data could be used with or with- out other meteorological data. Data preprocessing methods include data normalization, data imputation, outlier treatment, changing data resolution, data transformation, data augmentation, correlation analysis, data clustering, data modelling as a graph or grid, data decomposition, and features selection.

VI. RESEARCH METHODOLOGY

Deterministic forecasting models developed for solar and wind energies are divided into six categories according to the used architectures that are as follows:

A. Data normalization and denormalization

Normalization is an essential step when numerical values have different scales, which is the case with forecasting inputs. Ignoring this step, especially with gradient descent-based algorithms, hinders their learning process, and slow up their convergence speed towards the minima, thus, distort the performance results. Forty-four papers included in this review reported using normalization. It might have been used in the remaining papers, but not mentioned. The normalization technique used in almost all the papers is Min-Max scaling, which transfers the data into a range between 0 and 1.

B. Handling wrong or missing values and outliers

In most of the papers, it is mentioned that records contained wrong values or outliers were removed. However, replacing wrong values that are beyond the limit with the maximum value of that input variable is reported.

Also, missing values in this paper were filled using the linear interpolation method, in which an estimation of the value is calculated using the previous and the next value.

C. Data clustering

Clustering might be involved in renewable energy data pre- processing for dividing the dataset into different seasons or weather conditions. According to some researchers, the fuzzy c-mean clustering algorithm is recommended for this task. Historical PV power data was clustered into different groups to identify the daily pattern label. The k-means algorithm is used to cluster solar irradiance data into five clusters, which represent five types of sky conditions.

D. Linear Regression

The statistical method for linear regression needs to collect a large number of data related to the power output of the PV power generation system to regress some unknown constants and further obtain the functional relationship between the output power and the measurable unknown. According to the number of unknowns, the statistical method can be divided into the unary linear regression method, multiple linear regression method, and nonlinear regression method. Because there are many factors affecting PV system power generation, the prediction result is not satisfactory by using the unary linear regression method. The multiple linear regression method adopted that solar radiation intensity and ambient temperature as two main factors to build a multiple linear regression model of the PV system and finally obtains the linear function relation of the output power on six unknowns, including radiation intensity and temperature. By using this linear function, the output power of the PV power generation system can be predicted as long as the value of corresponding solar radiation and ambient temperature is obtained. Some researcher employs the support vector machine (SVM) to design a regression algorithm of the solar farm power prediction model. Because the SVM is based on the principle of risk minimization and has a strong ability of generalization, the error of solving results is relatively smaller even though there are fewer training samples.

E. Ridge Regression

The field of solar and photovoltaic (PV) forecasting is rapidly evolving. The electricity system in India faces several challenges as the energy demand is expected to grow significantly within the next decades while the domestic energy resources in terms of fossil fuels are limited. Hence it becomes important to get more dependent upon Renewable Energy to meet the future requirements. This project report provides state of the art of this dynamic research area, focusing on solar and PV forecast of next dates with given weather data. Diverse resources are used to generate solar and PV forecasts, ranging from measured weather and PV system data to satellite and sky imagery observations of clouds which form the basis of modern weather forecasting. Electric utility companies need accurate forecasts of energy production in order to have the right balance of renewable and fossil fuels available. Errors in the forecast could lead to large expenses for the utility from excess fuel consumption or emergency purchases of electricity from neighboring utilities. Power forecasts typically are derived from numerical weather prediction models, but statistical and machine learning techniques are increasingly being used in conjunction with the numerical models to produce more accurate forecasts. Forecasting methods can be broadly characterized as physical or statistical. The physical approach uses solar and PV models to generate PV forecasts, whereas the statistical approach relies primarily on past data to “train” models, with little or no reliance on solar and PV models.

VII. CONCLUSION

In this way renewable energy is necessary for the planet to remain sustainable is one of the important aspects that we understand from the above review. And we try to manage our power networks in significant manner so as to forecast the output of renewable energy in precise manner. Accurate forecasting of renewable energy generation is crucial to ensuring grid dependability and permanence and to reducing the risk and cost of the energy market and infrastructure became the research area for the new aspirants. Deep learning's recent success in a number of applications has attracted researchers' attention to this subject, and the range of proposed methodologies and the growing number of papers reflect deep learning's promising future.

REFERENCES

[1] Afshin Balal, Yaser Pakzad Jafarabadi, Ayda Demir, Morris Igene, Michael Giesselmann, Stephen Bayne, “Forecasting Solar Power Generation Utilizing Machine Learning Models in Lubbock”, Emerging Science Journal (ISSN: 2610-9182) Vol. 7, No. 4, August, 2023

[2] Louis Polleux, Gilles Guerassimoff, Jean-Paul Marmorat, John Sandoval Moreno, Thierry Schuhler, “An overview of the challenges of solar power integration in isolated industrial microgrids with reliability constraints”, HAL Id:hal-03467160, 2022

[3] Moon-Soo Song, Hong-Sik Yun, Jae-Joon Lee, Sang-Guk Yum4, “A Comparative Analysis of Machine Learning 1 Algorithms for Snowfall Prediction”, https://doi.org/10.5194/nhess-2022-118,

[4] Altaf Hussain, Zulfiqar Ahmad Khan, Tanveer Hussain, Fath U Min Ullah, Seungmin Rho, and Sung Wook Baik, “A Hybrid Deep Learning-Based Network for Photovoltaic Power Forecasting”, Hindawi Complexity, Volume 2022, Article ID 7040601, 12 pages, https://doi.org/10.1155/2022/7040601

[5] Zhigang Shi, Yuting Bai, Xuebo Jin, Xiaoyi Wang, Tingli Su and Jianlei Kong, “Deep Prediction Model Based on Dual Decomposition with Entropy and Frequency Statistics for Nonstationary Time Series”, Entropy 2022, 24, 360. https://doi.org/10.3390/e24030360

[6] Haoyin Ye1, Bo Yang, Yiming Han1 and Nuo Chen, “State-Of-The-Art Solar Energy Forecasting Approaches: Critical Potentials and Challenges”, Frontiers in Energy Research, www.frontiersin.org, March 2022, Volume 10, Article 875790

[7] Tamer Khatib, Ameera Gharaba, Zain Haj Hamad and Aladdin Masri, “Novel models for photovoltaic output current prediction based on short and uncertain dataset by using deep learning machines”, Energy Exploration & Exploitation 2022, Vol. 40(2) 724–748 DOI: 10.1177/01445987211068119 journals.sagepub.com/home/eea

[8] Giuseppe Marco Tina, Cristina Ventura, Sergio Ferlito and Saverio De Vito, “A State-of-Art-Review on Machine-Learning Based Methods for PV”, Appl. Sci. 2021, 11, 7550. https://doi.org/10.3390/app11167550

[9] Neelam Labhade-Kumar, Mangala S Biradar, Ashvini Narayan Pawale,"Reinforcement Learning-Based Deep FEFM for Blockchain Consensus Mechanism Optimization with Non-Linear Analysis"Journal of Computational Analysis and Applications, Vol. 33 No. 05 (2024)

[10] Berhane Darsene Dimd, Steve Völler, Umit Cali, and Ole-Morten Midtgård, “A Review of Machine Learning-Based Photovoltaic Output Power Forecasting: Nordic Context”, Digital Object Identifier 10.1109/ACCESS.2022.3156942, VOLUME 10, 2022

[11] Neelam Labhade-Kumar “Shot Boundary Detection Using Artificial Neural Network”, Advances in Signal and Data Processing. Lecture Notes in Electrical Engineering, Springer, Vol 703. PP-44-55 Jan-2021

[12] Tanveer Ahmada, Hongcai Zhanga, Biao Yana, “A review on renewable energy and electricity requirement forecasting models for smart grid and buildings”, https://doi.org/10.1016/j.scs.2020.102052, 2210-6707/ © 2020 Elsevier

[13] Neelam Labhade-Kumar “Experimental Design of Electricity Theft Detection and Alert System Using Arduino Assisted Controller and Smart Sensors"7th International Conference on Inventive Computation Technologies, IEEE Xplore Part Number : CFP24F70-ART ; ISBN : 979-8-3503-5929-9, 2024,PP-1961-1968

[14] Neelam Labhade-Kumar Optimizing Cluster Head Selection in Wireless Sensor Networks Using Mathematical Modeling and Statistical Analysis of The Hybrid Energy-Efficient Distributed (HEED) Algorithm, Communications on Applied Nonlinear Analysis, ISSN: 1074-133XVol 31 No. 6s (2024), PP-602-617 August 2024

[15] Jinliang Zhang, Zhongfu Tan, Yiming Wei, “An adaptive hybrid model for day-ahead photovoltaic output power Prediction”, https://doi.org/10.1016/j.jclepro.2019.118858 0959-6526/© 2019 Elsevier

[16] Zi Lin, Xiaolei Liu, “Wind power forecasting of an offshore wind turbine based on high frequency SCADA data and deep learning neural network”, https://doi.org/10.1016/j.energy.2020.117693 0360-5442, 2020 Elsevier

[17] Adel Mellit, Alessandro Massi Pavan, Emanuele Ogliari, Sonia Leva and Vanni Lughi, “Advanced Methods for Photovoltaic Output Power Forecasting: A Review”, Appl. Sci. 2020, 10, 487; doi:10.3390/app10020487

[18] Dr.Neelam Labhade-Kumar “Novel Management Trends Using IOT in Indian Automotive Spares Manufacturing Industries”, Journal of Pharmaceutical Negative Results , Vol. 13 ISSUE 09,PP 4887-4899, Nov-2022

[19] Rial A. Rajagukguk, Raden A. A. Ramadhan and Hyun-Jin Lee, “A Review on Deep Learning Models for Forecasting Time Series Data of Solar Irradiance and Photovoltaic Power”, Energies 2020, 13, 6623; doi:10.3390/en13246623

[20] Dr.Neelam Labhade-Kumar “Adaptive Hybrid Bird Swarm Optimization Based Efficient Transmission In WSN”, Journal of Pharmaceutical Negative Results, Vol. 14 ISSUE 02,PP-480-484, Jan-2023,

[21] Yunjun Yu, Junfei Cao, and Jianyong Zhu, “An LSTM Short-Term Solar Irradiance Forecasting Under Complicated Weather Conditions”, Vol. 7, 2019, Digital Object Identifier 10.1109/ACCESS.2019.2946057

[22] Ruiguo Yua, Zhiqiang Liua , Xuewei Lia , Wenhuan Lua, Degang Mad, Mei Yua, Jianrong Wanga, Bin Lie,” Scene learning: Deep convolutional networks for wind power prediction by embedding turbines into grid space”, https://doi.org/10.1016/j.apenergy.2019.01.010, 0306-2619/ © 2019 Elsevier

[23] Shuang Zhua, Xiaohui Yuanb, Zhanya Xua, Xiangang Luoa, Hairong Zhangc, “Gaussian mixture model coupled recurrent neural networks for wind speed interval forecast”, https://doi.org/10.1016/j.enconman.2019.06.083, 0196-8904/ © 2019 Elsevier

[24] Hui Liua, Chao Chena, Xinwei Lvb, Xing Wuc, Min Liud, “Deterministic wind energy forecasting: A review of intelligent predictors and auxiliary methods” https://doi.org/10.1016/j.enconman.2019.05.020, 0196-8904, 2019 Elsevier

[25] Shahab Shamshirband, Timon Rabczuk, and Kwok-Wing Chau, “A Survey of Deep Learning Techniques: Application in Wind and Solar Energy Resources”, Digital Object Identifier 10.1109/ACCESS.2017.Doi Number, IEEE

[26] Neelam Labhade-Kumar “Combining Hand-crafted Features and Deep Learning for Automatic Classification of Lung Cancer on CT Scans”, Journal of Artificial Intelligence and Technology, 2023

[27] Sourav Malakar, Saptarsi Goswami, Bhaswati Ganguli, Amlan Chakrabarti, Sugata Sen Roy, K. Boopathi, G. Rangaraj, “Designing a long short-term network for short-term forecasting of global horizontal irradiance”, SN Applied Sciences (2021) 3:477, https://doi.org/10.1007/s42452-021-04421-x

[28] Neelam Labhade-Kumar “Enhancing Crop Yield Prediction in Precision Agriculture through Sustainable Big Data Analytics and Deep Learning Techniques”, Carpathian Journal of Food Science and Technology,2023, Special Issue, 1-18

[29] Woonghee Lee, Keonwoo Kim, Junsep Park, Jinhee Kim, And Younghoon Kim, “Forecasting Solar Power Using Long-Short Term Memory and Convolutional Neural Networks”, Vol. 6, 2018, Digital Object Identifier 10.1109/ACCESS.2018.2883330

[30] Tuo Xie, Gang Zhang, Hongchi Liu, Fuchao Liu and Peidong Du, “A Hybrid Forecasting Method for Solar Output Power Based on Variational Mode Decomposition, Deep Belief Networks and Auto-Regressive Moving Average”, Appl. Sci. 2018, 8, 1901; doi:10.3390/app8101901

[31] Neelam Labhade-Kumar “Accident prevention and management system in urban VANET for improving slippery roads ride after rain” Journal of environmental protection and ecology, ISSN:1311-5065 Issue 2 volume 25,PP 586–599,2024

[32] Prof. Dr. Neelam Kumar, A Fast and Reliable Convolutional Neural Network Algorithm for Image Classification, ALOCHANA JOURNAL VOLUME: 11, ISSUE: 13, ISSN NO:2231-6329, PP-231-235, November 2024