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REVIEW ARTICLE

Artificial Intelligence Techniques for the Photovoltaic System: A Systematic Review and Analysis for Evaluation and Benchmarking

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Abstract

Novel algorithms and techniques are being developed for design, forecasting and maintenance in photovoltaic due to high computational costs and volume of data. Machine Learning, artificial intelligence techniques and algorithms provide automated, intelligent and history-based solutions for complex scenarios. This paper aims to identify through a systematic review and analysis the role of artificial intelligence algorithms in photovoltaic systems analysis and control. The main novelty of this work is the exploration of methodological insights in three different ways. The first approach is to investigate the applicability of artificial intelligence techniques in photovoltaic systems. The second approach is the computational study and analysis of data operations, failure predictors, maintenance assessment, safety response, photovoltaic installation issues, intelligent monitoring etc. All these factors are discussed along with the results after applying the artificial intelligence techniques on photovoltaic systems, exploring the challenges and limitations considering a wide variety of latest related manuscripts.

Abbreviations

ANFIS	Adaptive Neuro-Fuzzy Inference System
AI	Artificial Intelligence
ANN	Artificial Neural Network
ARMA	Auto Regressive Moving Average
AE	Autoencoders
ARIMA	Autoregressive Integrated Moving Average
COA	Cuckoo Optimisation Algorithm
DCNN	Deep Convolutional Neural Networks
DNN	Deep Neural Network
ELD	Economic Load dispatching
EMD	Empirical Mode Decomposition
ED	Event Detection
XAI	Explainable Artificial Intelligence
ELM	Extreme Learning Machine
FFNN	Feed Forward neural networks
FSPV	Floating Solar PV
FL	Fuzzy Logic
FCL	Fuzzy Logic Controller
GPR	Gaussian Process Regression
GRNN	Generalised Regression Neural Network
GA	Genetic Algorithm
LIME	Local Interpretable ModA24: B46el-Agnostic Explanations
LIME	Local Interpretable Model-Agnostic Explanations
LSTM	Long short-term memory
MAE	Mean Absolute Error
ML	Machine Learning
MCMC	Markov chain Monte Carlo
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
MLFFNN	Multi-Layer Feedforward Neural Network

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MLP	Multi-Layer Perceptron
MLR	Multiple Linear Regression
OPV	Organice Photovoltaic
PSC	Partial Shading Conditions
PSO	Particle Swarm Optimization
PV	Photovoltaic
P&O	Perturb and Observe
RNN	Recurrent Neural Network
RMSE	Root Mean Squared Error
SWDP	Seawater Desalination Plant
SHAP	Shapely Additive exPlanations
SHAP	Shapely Additive exPlanations
SVM	Support Vector Machines
SVR	Support Vector Regression
TEM	Thermoelectric Module
UC	Unit Commitment

1 Introduction

Global economic expansion is increasing the power market demand, causing a negative influence on the environment. The wholesale price of electricity has become an important aspect of the energy sector. Electricity is mainly traded in auctions known as power exchanges or pools, where electricity-generating companies provide energy together with pricing rates that can be bid on by essential consumers. Solar photovoltaic (PV) emerges as an alternative energy capable of meeting a greater percentage of global energy needs. Germany has developed by 20% for electricity generation and Japan is generating more PV power in the world, and 6.5% of global PV generation comes from this country. PV has become more cost-effective and the development of inorganic PV material aids in the efficient production of next-generation solar cells [1, 2]. As a result, operation and maintenance costs (O&M) have a critical impact on electrical and power module profitability margins, because energy market participants must forecast solar power in the medium and long term [3, 4].

The electricity price forecasting has become an important aspect of the energy sector [5], and Machine Learning (ML) Artificial intelligence (AI) algorithms approaches are widely implemented to recognise different patterns [6–8]. Despite the significant progress made using AI for PV generation, different challenges must be addressed to be resolved by future research focused on promising techniques based on AI, e.g., Explainable Artificial Intelligence (XAI) and novel hybrid techniques that reduce the weaknesses of current ML techniques to afford new PV operational scenarios required to reach the competitiveness in the energy sector [9, 10]. Different techniques for PV generation must work in a dynamic parameter environment, implying that agents cannot have complete awareness of the parameters and environment [11, 12]. Some research in the literature reviewed the issue of software failures, that may lead to inaccurate approximations [13–15]. The use of partial quantitative measurements and inconsistent information on the solar production environment in AI models can allow agents to operate in a variety of situations and restrictions, both at the users and the service provider levels [16]. The reviewed research literature demonstrates that several models have been employed for solar generating, with the benefits and drawbacks explored [1, 17, 18], demonstrating that there is a need to establish models and findings that are generally applicable to a wide variety of scenario. It is also required that the results are accurate, being the lack of modelling details a key problem across a wide part of the reviewed literature [19]. The accuracy of estimating PV system performance is constrained through the use of configuration models [20, 21], e.g., the Multiple Linear Regression (MLR) model is less effective than Artificial Neural Networks (ANN) in detecting hidden layers [22]. The performance of models has been affected by the dynamic parameters used for checking the efficiency of PV generation, showing low performance that affects the validity of this research study [23]. There is growing interest in identifying AI and ML to integrate real-time responses from other power channels interfacing with the power system, and this is considered to play a significant role in the future [24]. The adoption of more multi-agent frameworks, where agents can function in a simulated, stochastic environment while also relaxing assumptions about the preferences and expectations of participating entities, could be a promising approach for studies [25].

The fundamental objective of this study is to develop a new framework that can stimulate human-machine collaboration to estimate daily power prices in the wholesale market [26, 27]. The main novelties of this study are as follows:

- **Analysis of different frameworks**: The comparison of the power production using different PV cells is understood with the help of the review of different research papers. This section proposes a novel analysis of dynamic parameters used for checking the efficiency of PV generation that have a relevant influence on the performance of the models. The objective is to demonstrate that poor model performance affects the validity of research studies.
- **Analysis of various models with different parameters in PV generation**: Several models are used in the field of electricity forecasting, but these models have their advances and limitations. The objective of this study is to improve the traditional technologies in terms of accuracy and precision of prediction.

- **Analysis of the state of the art**: Several researchers have proposed different models for the same purposes. Recent research work done in electricity forecasting and the PV generation domain has been reviewed and analysed to select the best model and find novel approaches [28–30]. One of the most relevant novelties of the paper is an analysis of the state of the art performed in three different phases, that has not been found in the current literature:

    - **Review-based analysis**: The most recent studies in chronological order have been studied to analyze the main areas of the global energy industry under current investigation. The objective is to detect main trends and novel research lines.
    - **Method-based analysis**: The volume and variety of new studies and methods have grown exponentially in recent years, compared to traditional technologies. This phase analyzes new optimized and hybrid models to detect the most relevant and fastest-growing techniques.
    - **Result-based analysis**: The research outcomes achieved by the researchers according to the models they used, have been analysed in this phase.

This paper is structured as follows: Sect. 2 develops an analysis of the current state of the art based on different reviews, methodologies and results. Section 3 presents the overall discussion of the research, where all the applied methodologies and algorithms are summarized to extract relevant data about the state of the art. Finally, the main conclusions are provided in Sect. 4.

2 Related Work

2.1 Review Based Analysis

A new deep learning model is used for the enhancement of visual ability in PV generation [31]. The improvement of accuracy is the primary objective of the mainly with real-time data analysis [32, 33]. Figure 1 shows the basic process of the PV generation process. The radiant energy is absorbed by the PV panel or grid of PV panels [34]. This radiant energy is then converted into DC power and then it is passed to the power electronic converters [32, 35]. These converters convert the DC power into the grid frequency power [36].

Camargo and Schmidt [37] presented a survey to collect data from installations in Chile. The proposed hypothesis of the research focused on four data sets from PV installation. The multi-annual time series was simulated in the research, using forecasting and neighbour methods. It was demonstrated that deseasonalized aggregated data used to have a better correlation. The older MERRA-2 reanalysis dataset is the most critical limitation and the global reanalysis of the data set is one of the main advantages of this research. Guo et al. [38] suggested that PV plan installation is the most reliable and stable plan worldwide, and for this case study, solar power is used to limit the plan for PV generation. A prediction model algorithm is used in this research, analysing a short-term PV model. Boosting and bagging approaches were applied together with meteorological parameters and historical data as the main dataset. It is indicated that the cutting-edge plan of AI has predicted a new PV model. The single model was applied to act as a limitation in this context.

The primary objective of the study presented by Ogawa, and Mori [39] is to identify PV forecasting with an efficient method as a forecasting plan and a Multi-layer Perceptron (MLP) neural network. Two approaches based on ANNs and a statistical approach were implemented. The used dataset was distributed, and the error was normalised as a result of the MLP-based method. Under this PV plan, there is an issue or limitation such as Economic Load Dispatching (ELD) and Unit Commitment (UC). A Deep Neural Network (DNN) based method has been proposed by Dorokhova et al. [40], determining that PV generation has reduced the energy crisis and carbon emission plan positively. The control method, model predictive control and a reinforcement learning control data-driven approach were applied to a 2-year dataset. The electric vehicle charging problem was reduced by using reinforcement learning control, being confirmed that maximisation of PV consumption is highly required.

The primary objective of the research developed by Beltrán et al. [41] is to promote a novel framework to encourage the collaboration of human machines to forecast the price of electricity daily in the wholesale market. Model agnostic, time series analysis and time decomposition, STL, Holt-Winters, Bates and Granger method, Aiolfi and Timmermann method were applied to develop different approaches: loop approach, non-linear approach, and robust approach. Data stories depend on a model-agnostic method. The proposed framework was limited in grasping the bounds of point forecasts by marking the point intervals although it provided satisfactory results by increasing the computational power. Long Short-Term Memory (LSTM) framework was proposed to control the fault of ML algorithms, that are applied only to a huge volume of information [42]. Two-stage hybrid method, wrapper method, ML, deep learning, statistical methods and other forecasting approaches were applied. The robustness of LSTM was comparatively better than normal LSTM, demonstrating that a single framework

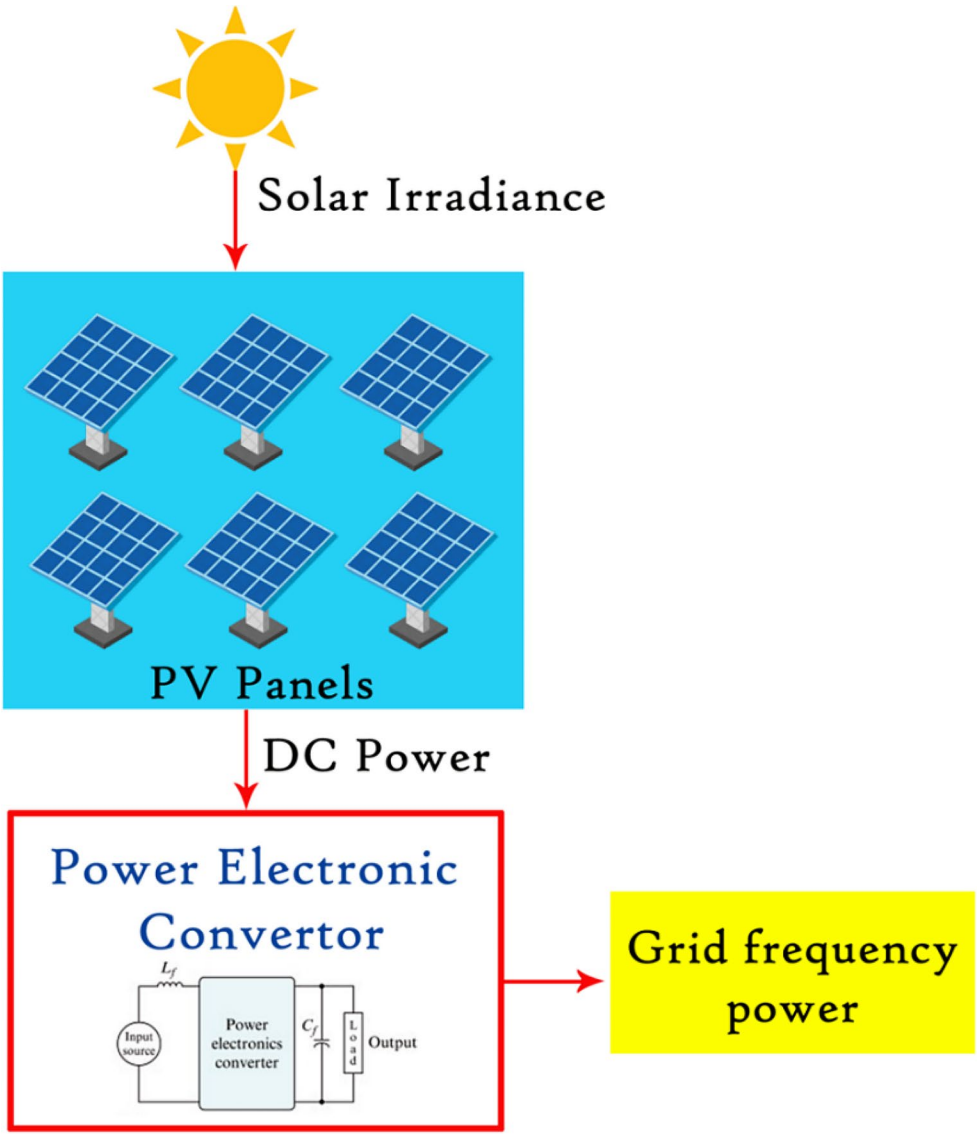

Fig. 1 General diagram of PV generation

is unable to predict PVPG accurately due to the bounds of the stand-alone process. Operators can solve time series forecasting issues due to the proper utilization of LSTM. PV generation is an effective solution that enables people to overcome the current energy challenges [36, 43]. Representing a relevant solar irradiation predictor that combines the benefits of ML and the optimization of temporal and spatial parameters is a survey objective of Rodríguez et al. [31]. ML and statistical methods, single model and AI approach were the main models. The accuracy of the results of feed-forward neural networks (FFNN) was better than the persistence model. The major limitation is the high training requirements for FFNN and spatial-temporal model but it is demonstrated that the solar irradiation predictor was able to accurately measure certain changes.

Dynamic power flow, regression, and two core-casting methods were chosen together with the DL approach with time sequence and time-series data. Distribution losses have been found while using secondary and primary LSTM systems. The major drawback of this proposed mechanism is the absence of voltage collapse mitigation and limit violation according to Yin et al. [44]. Visser et al. [45] proposed the performance analysis of 12 different models for forecasting the day-ahead power production with an agreement to the market conditions. The objective of the research was to examine the effect of multiple PV systems with a variation in the inter-system distance on the performance of forecasted models. The method of clean data has been used to analyse 12 different models with their pre and post-processing phases. The direct and indirect approach has been chosen to analyze the PV model, regression and ML-based models. The dataset is formed by PV power output from 152 PV systems located in the Netherlands. The result of the research showed that density and spatial factors presented a

positive effect on the performance of the models. The limitation of the research was related to the testing conditions as many cases are of a single site or single aggression of several systems. The advantage of the research was related about the managers of the power grid will be able to minimise the grid imbalances with the application of the models.

The research developed by Gowid and Massoud [46] designed a tool to identify robust and practical PV Maximum Power Point (MPP) with the use of reliable experimental data. They performed a comparative study of input scenarios and developed a novel tool, being necessary to develop a correlation between the current at the maximum power point I_{MP} and the maximum power voltage V_{MP} with PV electrical, thermal, and meteorological variables. The MPP approach was implemented to conduct the research, and the results displayed a decrease of 74.3% in MSE of V_{MP} and a reduction by 95% in the MSE of I_{MP}. The parameter combination scenarios were restricted to maximize the accuracy in the research, although this tool will help to maximise the power output. A novel research was developed by Tian et al. [47] to analyse the feasibility and necessity of connection of PV power generation introduction into rail transit power supply. The authors applied the indirect forecasting method for forecasting the load of PV power generation. The LSTM neural network approach has been adopted in the research and the data of the research has been collected from a PV power station every 10 min for 207 days. The LSTM neural network results presented elevated levels of fitting and high prediction accuracy. There is no research limitation in the paper and the benefit of the research is that the capability of the LSTM neural network is well known. The application of ML and data-driven techniques at the level of monitoring, controlling, optimisation and fault detection of power generation systems was applied by Sun and You [48]. The main objective is the analysis of ML and data-driven techniques in terms of flexibility and profitability. ML and data-driven methods were used together with FT, Bayesian nonparametric and Markov chain Monte Carlo (MCMC) approaches. The results showed that big data ML-based methods of regression seemed to be more powerful in characterising nonlinear multivariable systems, although this control method had a limitation of dealing with high uncertainty and nonlinearity. The research will benefit in showing the ML-based data in control, visibility, profitability, and safety during power generation. These factors are essential to ensure a proper data analytics process, and Fig. 2 illustrates how much these factors can be achieved through the ML techniques applied in this section, showing a basic comparison of ML usage in the aspects of visibility, manoeuvrability, flexibility, profitability at intervals of significance of these features.

PV forecasting is another relevant research topic. The research developed by Behera et al. [49] analysed short-term PV power forecasting by the Empirical Mode Decomposition (EMD) technique. The objective of the research is to construct a 3-stage approach and analyse the PV power forecasting with the constructed approach. Statistical methods were used to analyse the historical solar irradiance data and the 3-stage approach of the EMD technique was implemented. The result of the analysis of the collected data showed that EMD techniques have performed better than the conventional technique with the address to short-term PV power forecasting. High reliability, optimal placement, acceptable power quality and low-cost operation are a few factors that are the limitations of the application of solar power. The background of the research is based on the implementation of the ML network for yielding promising solutions in pattern recognition and low estimation bias.

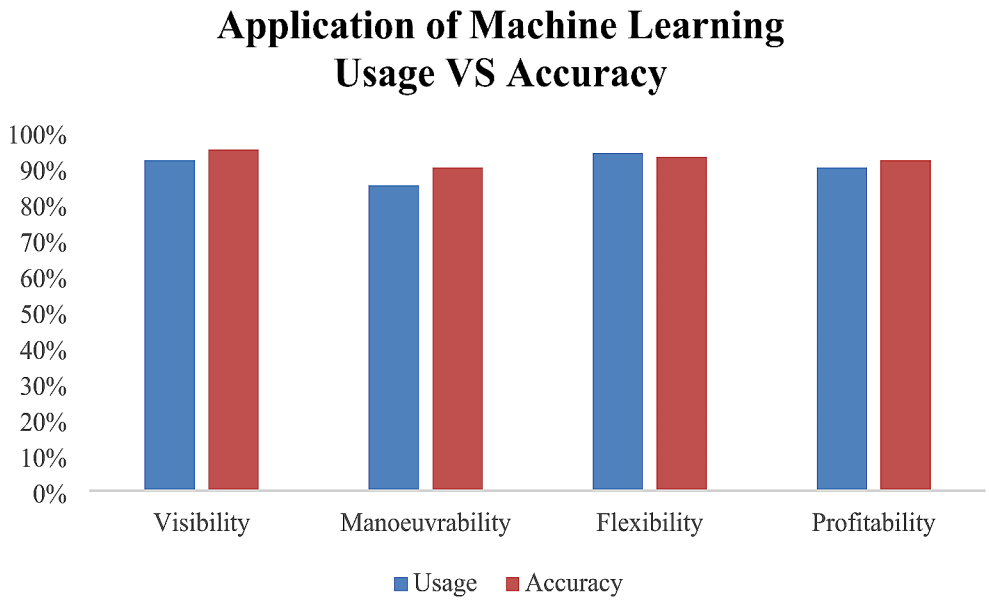

Fig. 2 Comparison of various ML factors in terms of usage and accuracy

According to Khodayar et al. [50], the objective set for the study is to discriminative deep models to estimate future solar energy as per the historical measurements. The statistical method of generative variation based on autoencoders (AE) was used to estimate the disaggregated BTM signals. The Pecan Street dataset was used to carry out the research, and the numerical results of the real-world Event Detection (ED) dataset showed significant improvements in ED accuracy to sparse coding approaches. There are problems of energy disaggregation in PV penetration in the sparse coding approaches but the application of multiple deep ANN can increase the prediction accuracy.

The development of Floating Solar PV (FSPV) systems is in the nascent stages of long-term performance and its feasibility was not effectively addressed by Goswami et al. [51]. The analytical method used for the mathematical modelling of the PV cell to develop a computational method was based on evolutionary algorithms for the assessment of FSPV. The numerical approach was used in the research for the determination of parameters although there was no dataset applicable. The proposed model applied on 100 FSPV modules showed superiority in the estimation of its parameters and the efficiency of the model decreased under low irradiance. The research findings will help in the sound judgments of the scientists with the implementation of the FSPV systems. The discovery of the inorganic PV material helps in the effective ways of generating new-age solar cells [52]. Predicting the efficiency of inorganic PV materials with relevant ML is the primary objective of the survey. The use of ML method was used along with density functional calculations in material discoveries. The ML approach was issued for the study to recognise the patterns between materials using three datasets as the input, training, and production datasets. The results showed that the ML method was an effective method for fast atomic level prediction of PV materials [52]. The author did not point out any disadvantages related to the study. The application of ML helps in the accuracy of prediction regarding the PV materials of different crystal structures. The use of solar energy is used by countries to decrease ecological hazards. The Root Mean Squared Error (RMSE), mean absolute error and R^2 model were used to explore the relationship between numerous input parameters and solar PV using ML models [9]. ML and predictive approaches have been used for the research, using experimental datasets. The results showed that the proposed ML approach was accurate at predicting the power of different solar PV panels. The effect of dust and wind on solar PV is still incomplete in terms of experiments, but the Support Vector Machine (SVM) and the Gaussian Process Regression (GPR) models enhanced the forecasting of solar PV power.

The lack of weather information affects the theoretical power calculations and focuses on the whole power station rather than the arrays, according to Liang et al. [53]. A data-driven method was used along with the Extreme Learning Machine (ELM) model to solve the problem through the status evaluation method of arrays. Six arrays were selected on a random basis from the large-scale power station in China and a statistical approach was implemented for the evaluation of the data. The results demonstrated that the status assessment accuracy was 90%, confirming its effectiveness. The main contribution of this study is the identification of the proposed method to reflect the status of PV arrays, although the evaluation of the degradation of the PV arrays was not possible through the current method. The primary objective of the analysis carried out by Kalogirou and Sencan [54] is to analyse the international PV market and forecast the market demands and developments in 2010. The basic methods used in this research calculated manufacturing costs, identified production efficiencies, and then forecasted the PV world market. A profitable approach and single crystal silicon module were implemented in this research. The dataset for this research is formed by datasets of the PV world market, PV production efficiencies and manufacturing PV costs dataset. Due to the practical limit of advanced technology, forecasted data on the development and market demand of PV may not be accurate. The focus of the research is to examine the possibility of utilising AI in forecasting the production of PV energy using Auto-Regressive Moving Averages and regression methods. Energy production management, moving averages, data-driven modelling, and classical approaches have been implemented by Maycock [55] to forecast the production of electricity. The initial Production Dataset (PD and SI) was inspected in this research. The simulation result showed that MFNN can be effectively used by operators to predict the energy production by the unit of PV production. Lack of better precision determines an enhanced complexity of the ANN model resulting in decreasing the lesser accuracy value in predicted data.

Hossain et al. [56] presented a forecasting algorithm with an LSTM ANN to predict PV power generation. This work applied a statistical analytical research method with three years of (2016–2018) based simulation. The implementation of synthetic irradiance forecast can improve by up to 33% in accuracy compared to using the hourly categorical type of sky forecast. The superiority of the LSTM ANN with the proposed features was tested by exploring other machine learning algorithms, such as the recurrent neural network, the Generalised Regression Neural Network (GRNN) and the ELM. Almomani et al. [57]. presented a method for modelling PV arrays based on AI techniques, specifically Genetic Algorithm (GA) and Cuckoo Optimisation

Algorithm (COA). The adopted models using GA and COA were implemented in a simulation platform using MATLAB environment for two-diode and two-diode and single-diode models. The obtained models were tested and validated with experimental data taken from the PV power plant at Mutah University. The results showed that for both optimisation algorithms, the two-diode model was more accurate than the single-diode model. The results also revealed that, at different values of temperature and solar irradiance, the COA handled the optimisation problem better with low iterations and better fitness value compared to the GA.

Solar energy is extremely dependent on climate and geography, and fluctuates irregularly, making the integration of PV into power networks problematic. Ahmed et al. [28] reviewed and evaluated contemporary forecasting techniques. Input correlation analysis revealed that solar irradiance is most correlated with PV production, and for this reason, meteorological classification and cloud movement studies are crucial. Normalisation, wavelet transforms, and augmentation by a generative adversarial network were recommended for network training and forecasting. The authors discussed the established performance evaluation metrics Mean Absolute Error (MAE), RMSE and mean absolute percentage error, with suggestions for including economic utility metrics of economic utility.

Different optimization and control techniques were widely proposed to address four issues including intermittent power supply, low conversion efficiency, the nonlinearity of PV system, and high fabrication costs [10]. Institutive method, ML methods (supervised and unsupervised learning methods), ANN forecasting method, simulated Annealing, SVM, and Harmony Search approach were applied to a large dataset of solar radiation. SVM was the best fit for reducing the RMSE and MAE values. The calculated RMSE value was 12.41% and the MAE value was 6.95% after using the SVM technique. Weather prediction in a geographic region may not be accurate because it shows a minimum error. The main objective of this research developed by Das et al. [58] is to inspect the progress of solar technology development and explain the innovative path. The Wille method and hierarchical clustering method were applied together with silhouette validation, and paragraph vectors doc2vec and word2vec, together with ML approach. The experimental dataset demonstrated the impacts of changing parameters on the system of storage and limitations in installing and purchasing solar power. Solar power technology may reach competitiveness in the global marketplace following this research.

Kaliappan et al. [59] used ANNs to predict the reduction in energy consumption of buildings that would result from installing a new photovoltaic system. This research studies the efficiency of the Elman Neural Network (EN) method, FFNN, and GRNN. The findings of this paper showed that forecasters using ANNs improve accuracy when employing the previous methods (EN-FFNN-GRN). A review of the AI-based Maximum Power Point Tracking (MPPT) in the solar power system was carried out by Yap et al. [60]. Since conventional MPPT techniques are unable to track the global maximum power point under Partial Shading Conditions (PSC), it is necessary to introduce artificial intelligence techniques to enhance this method [34, 61]. A model-based approach has been used to review the specific MPPT open-circuit voltage. Irradiance data has been employed to improve the accuracy of the MPPT prediction. The results demonstrated that all AI-based MPPT techniques showed faster convergence speed, lower steady-state oscillation and higher efficiency compared to conventional MPPT techniques, although the computational cost was also higher. This work provided a detailed comparison of popular highways MPPT techniques for solar power systems. Zhang et al. [62] applied Deep Convolutional Neural Networks (DCNN) with high-resolution weather forecast data to analyse the cloud movement pattern and its effect on solar power generation forecasting for solar farms. In this research work, the error rate is significantly reduced in comparison with other methods, e.g., the persistent model, the Support Vector Regression (SVR) model and convolutional neural networks. Therefore, it is exposed that solar forecasting DL outperforms sophisticated physical models.

Ai-Habahbeh et al. [63] used Auto Regressive Moving Average (ARMA) and Autoregressive Integrated Moving Average (ARIMA) methods to achieve a large improvement in PV performance. The parameters of the CNN participation model also optimised the performance. The study aimed to build a suitable model and test it using a simulation method. The result of the study showed a strong influence of temperature and the amount of sunlight, being the main advantage of this approach the reduction and elimination of waiting time. In addition, energy generation was discussed as a vital outcome that is essential for climate change. Digital twinning is a novel technique that provides a virtual representation of a real-world physical system or process (a physical twin) that functions as an indistinguishable digital counterpart for practical purposes such as simulation. The research work developed by Mazhar et al. [64] provided a systematic review of the integration of Big Data, ML and AI techniques with digital twinning. This paper focused on the role of big data and AI-ML in the creation of Digital Twins (DT) or DT-based systems for various industrial applications. The final section highlights the research potential of the IA-ML for digital twinning, mentioning different challenges and current opportunities.

Different ways for the operation of smart amplification building systems were presented by Hussin et al. [65]. The

authors maximised the use of solar energy and improved the transformation efficiency by using two fundamental MPPT methods, e.g., incremental conductance method and disturbance observation method. According to the obtained results, the MPPT algorithm was used to control the voltage level and restrain the current of the photovoltaic cells at the minimum value, and the actual conversion power was limited affecting the output power of the PV cells. It is concluded that solar energy is cost-effective for commercial purposes due to the reduction of the overall costs of electricity generation and consumption. Gligor et al. [66] applied a Multi-Layer Feedforward Neural Network (MLFFNN) to forecast PV production. Different configurations of the MLFFNN were compared to forecast one-day production based on a one-day versus a ten-day regression window. The accurate results determined that this particular type of ANN was suitable for the forecasting of energy production generated by PV modules, obtaining better precision in the prediction with this regression window.

The aim of Kihlström and Elbe [67] was to acquire conclusions about PV technology in the market through market interventions over 40 years. A systematic literature review of peer-reviewed studies on PV technology and market interventions from 1979 to 2019 was provided. Solar PV technology has faced several financial and structural market barriers, including stable governmental market interventions. This article predicts that PV can be an "attractive energy alternative" in the future and a core technology that can develop the specific segment in a solar PV system. The aim of the study performed by Tived [13] is to obtain a review of AI in the solar PV value chain, its current application and future perspectives. Systematic search and statistical combination of quantitative study have been used with a hybrid approach using SVR, Particle Swarm Optimization (PSO) and SVM. The data was presented as a time series, applying different evolutionary algorithms, e.g., PSO and GA. The potential of AI systems and applications promoted the objectives of the European Green Deal, being illustrated through numerous scenarios that direct and indirect adverse have a relevant impact on the environment. The authors also concluded that environmental policies and regulations should be focused on creating a better regulatory vision. Gailhofer et al. [30] discussed specific funding needs for research and development since it is improbable that AI applications can be developed to support government activities related to monitoring, planning or infrastructure without public funding.

The work of Kalaiarasi et al. [68] applied MPPT to track the maximum available power of solar PV systems. A comparative study of various AI-based MPPT techniques, e.g., Fuzzy, ANN and Adaptive Neuro Fuzzy Inference System (ANFIS), was carried out. The output of the PV module interfaces with the resistive load through the Z-source inverter that boosts the input voltage and provides an AC output voltage. This configuration is implemented to find out the experimental remark regarding the PV array. Under the context of the method, modelling PV has been used by Ghannam et al. [69]. A novel approach of AI combined with cell dataset information was implemented. Optimisation algorithms have been developed through the diode model, being the boundary limits of the segment as the main limitations while maximum valid stimulation is the main advantage. Climate perturbations are increasingly unpredictable and powerful, being required revisions of the global horizontal irradiation and direct normal irradiation calculation models. Othman et al. [70] used DL as a tool to forecast the behaviour of the production of any geographical site. Different databases from NASA and the Tunisian National Institute of Meteorology were deployed for the climatic parameters of the study region of El Akarit, Gabes, Tunisia to achieve this objective. The use of DL algorithms validated previously made estimates of the energy potential in the studied region. Different techniques were applied and compared, obtaining an overall accuracy rate of around 75%.

A real grid-connected Seawater Desalination Plant (SWDP) in Egypt is implemented using MATLAB/SIMULINK by Ebrahim et al. [71]. The developed power plant consists of a PV array, a DC/AC converter, the load and the grid. Three MPPT controllers were explored in this study to improve the dynamic performance of the proposed grid-powered SWDP to address the low conversion efficiency of the PV system. Incremental conductance along with three artificial optimisation techniques (PSO, grey wolf optimisation and Harris hawk optimisation) were developed for the dynamic performance evaluation of the presented PV-powered SWDP. The results obtained from the three methods were promising in extracting maximum power with minimum error from the PV system and improving the performance of the SWDP The objective of Khan et al. [72] is the revision of the AI-based nonlinear integral backstepping control approach for maximum power extraction of stand-alone PV system using buck-boost converter. The results from the simulation showed that the integral backstepping technique outperforms the conventional Perturb and Observe (P&O) MPPT technique in all scenarios under varying load and environmental conditions with faults and uncertainty in terms of fast reaction time and minimum tracking error. Kahdka et al. [73] proposed an ML-based decision-making model scheme to optimise the cleaning interventions of PV modules. This paper analyses different PV panel cleaning practices for different types of PV cells and different cooling methods, identifying the main parameters on which to base cleaning optimisation. The researchers

had to face challenges in data selection and data processing that may generate limitations. This study also provided a brief understanding of the current cleaning system of PV solar panels and a future perspective of the cleaning system.

Understanding the underlying inner workings of an AI-based forecasting model can provide insight into the field of application. This knowledge enables us to improve solar PV forecasting models and highlight relevant parameters. XAI is an emerging field of research in the smart grid domain and it helps to understand why the AI system made a forecasting decision. The work of Kuzlu et al. [74] presented several use cases of solar PV forecasting using XAI tools, such as Local Interpretable Model-Agnostic Explanations (LIME), Shapely Additive exPlanations (SHAP) and ELI5, that can contribute to the adoption of XAI tools for smart grid applications. An understanding of automation detection is provided by Sarp et al. [75] using explainable XAI in calculating the input and output of solar PV power. The data is tested and trained with an explanatory approach, that uses the calculation of the RMSE metric as an evaluation method. The main conclusion is that the XAI model helps understand the current advantages of PV with its use. The research paper developed by Esen et al. [76] analysed the influence of timestamps, forecast horizons, input correlation analysis, data pre- and post-processing, meteorological classification, grid optimisation, uncertainty quantification and performance evaluations in PV production analysis. The study focused on the introduction of solar and radiation simulators for PV research. The prototype solar LED system used in this research was examined using numerical formulas, in addition, emphasis is placed on PV tests based on a statistical approach. The tests were carried out with results below 2%, being considered as Class A. This research helps to understand that the use of solar simulators requiring few LEDs may occur in the future.

The efficiency of solar cells decreases with the increased temperature. The study objective was developed by Benghanem and Almohammedi in one of the hottest places in the world to reduce the temperature of the solar cells and improve their efficiency [77]. In this research, the Thermoelectric Module (TEM) was used for the analysis of performance. The results of the study showed that the efficiency of the solar panels dropped by 0,5% with a per degree rise in Celsius. The best performance of PV/TEM is only applicable in hot areas. The study helped in the suggestion of the hybrid PV/TEM for future use. Organic PV (OPV) cells are based on the concept of polymer-fullerene bulk hetero junction and are interesting due to their low cost and flexibility [78]. The objective of the study was to optimise the tandem structure composed of OPV cells based on the blend materials of P3HT through a transfer matrix simulation approach, various software and simulations. Optical Thickness data of OPV cells have been collected for the software simulation and the two wavelengths showed a good distribution of 500 nm and 727 nm. It is concluded that the model helps in the application of the OPV cells. To make a simulation on strained GaAsxP1-x and tensile train GaNyAsxP1-x-y in the quantum zones that are well active to get it inserted in the solar cells. Chenini et al. [29] used the band anticrossing model to explain the dependencies of lower E- and lower E + sub-band energies of the nitrogen concentration. The donor-acceptor approach has been used in this study for preparing low bandgap polymers concluding that the introduction of arsenic into the host material leads to the reduction of the bandgap energy. The limitation of the study was based on semiconductors although this study will help in increasing the absorption and redshift in the corresponding wavelength.

OPV cells are considered third-generation solar cells featuring new materials, such as organic polymer and tandem solar cells. The aim of the study developed by Benghanem and Almohammedi [77] is to analyse various materials, devices and fabrication techniques for OPV cells. Several roll-to-roll techniques have been used for the design of OPV cells and the slot die coating approach was used for coating the materials. The result of the study showed an increment of 8% efficiency for manufactured PV panels with special conditions and techniques. The limitation of the study is the lack of accuracy to demonstrate this efficiency.

2.2 Summary Review-Based Analysis

The summary review-based analysis is shown in Table 1. The comparison of energy production using different PV cells is understood with the help of the review conducted in this paper. DL has been demonstrated to be very useful for recognising the PV power generation pattern, and the Physic Constrained-LSTM model boosts in superior prediction performance of solar PV cells in temperature prediction accuracy. Conventional techniques e.g., PSO, ARMA or ARIMA, are being outperformed but advanced techniques based on AI due to their suitability and high accuracy in different scenarios and case studies presented by several authors. It is important to highlight the applicability of ELM and k-means due to high accuracies around approximately 90%, being the ML Matern 5/2 GPR method one the most optimal methods in performance for solar PV power prediction. XAI has proven to be one of the most relevant techniques and the number of research papers that have applied these techniques has grown in the last years. XAI has been proposed as a relevant solution for PV forecasting due to high performance, scalability or reduction of errors, among others.

Table 1 Summary of various studies based on review-based analysis

Journal citation	Methods	Advantages	Disadvantages	Performance
Das et al., 2018 [58]	An ML approach that combines the Wille method, hierarchical clustering, silhouette validation, and paragraph vectors doc2vec and word2vec.	ANN and SVM-based forecasting models give accurate results despite varying environmental conditions.	Despite the advantages, the range of the observed error was high due to different weather conditions.	The proposed optimized algorithm increased the forecasting accuracy of the model making GA one of the most viable optimization methods.
Zhang et al., 2018 [62]	Different DL models for solar energy output forecast	DL results demonstrated its strength for this particular scenario.	The authors applied a one-hour time interval expansion, but greater values may affect the performance due noises to in the input data.	The error was reduced from 21% to 15,1% in the SVR model, obtaining 11.8% in CNN.
Gligor et al., 2018 [66]	Multi-layer Feedforward ANN for the analysis of energy production in PV installations. The training dataset was formed by 30 months of a working PV plant.	With high reliability in energy estimation, the structure of the ANN is suitable for this type of problem.	Increments in precision are required due to higher computational costs caused by the complexity of the ANN	Different configurations were tested to estimate electricity generation. The authors proposed two case studies, obtaining RMSE between 0.1577 and 0.21456.
Ghannam et al., 2019 [69].	ML techniques, e.g., GRNN, FNNN, MLP and CFNN, were used for the prediction of solar radiation	The obtained results showed the high accuracy of ML and AI techniques in all scenarios in comparison to conventional analytical methods	This study is formed by different simulated scenarios, being required working PV plant to test the methodologies	The mean absolute percentage error of the different ANNs was between 6.5% and 19%, making it possible to confirm that the forecasting is accurate in all the cases.
Camargo and Schmidt, 2020 [37]	The annual time series was simulated in the research, using forecasting and neighbour methods in 23 large PV plants.	Deseasonalized aggregated data had a better correlation. The global re-analysis of the data set is one of the main improvements of this research	The older MERRA-2 reanalysis dataset is the most critical limitation, reducing the reliability of the results	Correlation values were defined between 0.8 and 0.9, with root mean square errors around 0.2.
Guo et al., 2020 [38]	The predictions were performed with eXtreme Gradient Boosting	The authors presented a stacking methodology that combined different models to acquire the main capabilities of each algorithm and complement each other's.	This design may fall into a local smallest during the optimization process.	The scores of all the scenarios were defined around 90 with prediction results showing that the RMS of Stacking is 0.1007, 1.84% lower than XGBoost.
Ogawa and Mori, 2020 [39]	DNN-based method, Generalized Radial Basis Function Network and ANN. This structure is compared with other methods, E.g., PSO, and MLP.	The method proposed by the authors presented the most reduced forecasting errors.	The definition of the entire model increases the complexity of the analysis, requiring different cost functions and methods.	The average mean normalized error was defined as around 0.24, compared with other methods that obtain values between 0.34 and 0.82.
Gowid and Massoud, 2020 [46]	Different ANNs were tested in four scenarios for MPP identification.	The performance of the proposed method achieved high dynamic response and	Training, validation, and testing of the proposed ANN models were developed using experimental laboratory data, being required data from working PV plants.	MPP prediction performance of 99.6%
Behera and Nayak, 2020 [49]	The authors combined EMD, sine cosine algorithm and ELM. The datasets were defined in 15, 30 and 60 min for short-term forecasting of PV	The high reliability of the results and the similarities between the techniques.	The training of the different methods increases the complexity of the modelling. The size of the dataset has a relevant influence on the results	The combined techniques with the 15-minute data approach provide the best performance among most of the cases with the lowest MAPE of 1.8852%.
Hossain and Mahmood, 2020 [56]	LSTM network and K-means algorithms are applied for PV power generation forecasting, being compared with GRNN and ELM.	The implementation of synthetic irradiance forecasting provided 33% improved accuracy for real forecasting.	The time window for prediction was defined as 24 h, being limited and affected by the synthetic irradiance.	LSTM achieved the lowest RMSE of 0.71 and MAPE (22.31%), compared with GRNN and ELM.

Table 1 (continued)

Journal citation	Methods	Advantages	Disadvantages	Performance
Yap et al., 2020 [60].	Different AI-based MPPT techniques (ANN, GA, ML, swarm intelligence…) were compared under PSC	The steady-state oscillation in each case is reduced, obtaining a maximum of 10% for GA.	The authors proposed simulated scenarios, requiring working PV plants. The selection of each AI-based MPPT is not obtained from the conclusions.	Swarm intelligence worked properly with the minimum tracking time.
Kuzlu et al., 2020 [74]	AI-based approaches with LIME, SHAP and ELI5	LIME demonstrated to be faster than SHAP, although SHAP provided a full explanation of predictions.	LIME did not provide a perfect distribution of the simulated effects. ELI5 is the most limited technique.	LIME provided 7.236% RMSE, SHAP 7.216% and ELI5 7.235%.
Dorokhova et al., 2021 [40]	ML techniques focused on deep reinforcement learning for electric vehicle charging.	Different reinforcement learning techniques conflicted and did not provide accurate results.	one can choose to switch from single agent to multiagent methodology to explore how RL agents cooperate towards common or competitive goals.	The authors compared the methodologies based on the execution time of train datasets.
Luo et al., 2021 [42]	A physics-constrained LSTM network for forecasting, being compared with other techniques, e.g., ARMA or FCNN.	The model also demonstrated high performance and accuracy recasting compared to conventional machine learning and statistical methods.	The authors aimed to overcome the weaknesses of recent ML algorithms that produce unreasonable forecasting. It requires more tests or scenarios to test the viability of the methodology.	The minimum MAE was obtained for the physic-constrained LSTM in both PV plants proposed in this case study.
Tian et al., 2021 [47]	LSTM is used for PV power generation prediction.	LSTM neural network presented high prediction accuracy, ensuring proper stability of the power supply system. The training data is formed by more than 200 days.	The authors did not provide details about the scenarios or the results, making necessary more comparatives to ensure proper reliability of the method.	The authors compared the prediction with the observed scenario, although the error between these options must be provided to compare the accuracy of the results.
Liang et al., 2021 [53]	ELM is implemented together with the k-means algorithm.	A real case study with a 40-MW power station is presented.	The authors demonstrated that the performance of PV arrays is degraded constantly, which is necessary for the evaluation of the real status. The status indicators have a relevant influence on the accuracy of the classification method, requiring an advanced search for the best indicators to achieve optimal classification accuracy.	The method developed by the authors presented a high accuracy with an RMSE around of 8%. The k-means algorithm was also applied to validate the accuracy, obtaining 85%.
Kaliappan et al., 2021 [59]	ANN, EN method, FFNN, and GRNN	The main advantage is that the model does not rely on simulation or configuration, achieving high accuracy and reliability in the forecasting process.	The complexity of the model is increased due to the combination of techniques with different characteristics.	EN, FFN, and GRN had the RMSE of 0.25, 0.37, and 0.45, respectively. The EN-FFN-GRN model had relative error values between − 1.5% and 1.5% for 94% and 98% of the samples.
Kalaiarasi et al., 2021 [68]	AI-based MPPT controllers based on ANN and ANFIS, among others.	The authors presented a method validated with different simulations	The training information on the different implemented methodologies was not presented in the paper.	ANFIS provided better results than ANN and fuzzy-based MPPT, reaching 0.8 of permanence.
Ebrahim et al., 2021 [71]	PSO, grey wolf optimisation and Harris hawk optimisation	A real case study is presented to optimize the electrical load on a SWDP. The comparison between the different techniques allows to future researchers to apply the most suitable technique.	Different unstable results were obtained for Harris hawk optimisation.	The results for Harris hawk optimisation showed low accuracy, providing local optimum solutions during the tuning process. PSO and grey wolf optimisation presented better results although more indicators are required to obtain conclusions about the techniques and the scenarios.

Table 1 (continued)

Journal citation	Methods	Advantages	Disadvantages	Performance
Sarp et al., 2021 [75]	XAI tools were applied for	The authors presented different features to be included in the model. ELI5 was also included to test the reliability of XAI for PV forecasting.	The dataset must be improved to test the viability of the methodology with larger datasets.	The inclusion of all the features reduced the RMSE scores (7.22 in comparison with 8.98)
Beltrán et al., 2022 [41]	A novel architecture that applied AutoML, an IoT platform for modelling. Different decompositions were proposed based on Seasonal and trend decomposition, or discrete wavelet transform, among others	The individual advantages of each approach are highlighted, to individually characterize the electricity price series. This approach has been demonstrated to be useful for prediction outcomes with changes in feature values	The authors did not detect significant improvement in ensemble stacked architecture	The forecasting results showed high accuracy on MEA, around 1.859, and a mean absolute scaled error of 0.378.
Visser et al., 2022 [45]	The performance of 12 different models, e.g., LSTM, ANN or random forest, were compared for the analysis of economic performance.	The performance of different models was obtained, making it possible to determine the strengths and weaknesses of each one.	MAE is not properly analyzed, being required further research to determine the error of forecasting models.	LSTM performance is higher than the other models.
Goswami et al., 2022 [51]	Different methods, e.g., PSO, Simulated Annealing or Repaired Adaptive Differential Evolution, were implemented	Shading conditions were simulated, providing reliable results for predicted and experimental values.	The authors presented an experimental setup of PV modules, being required real experiments to test the viability of the method.	The parameters extracted using the proposed method had a low RMSE value of 9.83002E-04. The relative error without shading conditions was 0.57% while for an overcast day, it was 0.89%.
Brester et al., 2023 [79]	MLP and LSTM ANN for one day-ahead solar PV forecasting being compared with a physical model.	The authors applied different training parameters combined with weather observations, that increase the reliability of the methodology.	The authors provided different scenarios that did not increase the understanding of the results	The MAE of the physical model was always higher than MLP, obtaining a 3% relative decrease.
Sarmas et al., 2023 [80]	Multiple LSTM models for one-hour ahead PV forecasting in 3 PV plants.	High scalability and adaptability, demonstrated with reliable results in different PV plants,	The selection of the parameters of each model has a relevant influence on the overall performance, and this has not been explored by the authors,	The proposed model increased the accuracy by up to 5%.

2.3 Method Based Analysis

The method-based analysis compares different studies and methods, their performance, advantages and disadvantages, as it is observed in Table 2. The purpose of this section is to demonstrate the main technologies of AI techniques utilised in power systems to improve traditional methods. In most of the research studies, multi-objective optimisation methods, multiple linear regressions and ANN methods have been used obtaining results with high accuracy in different case studies, e.g., rate of output of hydropower. This analysis verifies the computational efficiency of the proposed methods. The results revealed that among several AI techniques, ANN has emerged as one of the most effective methodologies for PV solar forecasting, surpassing the capabilities of GA or fuzzy logic. These research works reveal the operating ways of AI and other ML methods to forecast and improve the output power in the PV operation. Different techniques have shown limitations, e.g., reduction in estimation capabilities, that decrease the reliability of the overall analysis. It has been demonstrated the influence of the sampling rate in the obtention of reliable results required suitable datasets to overpass 80% accuracy. Moreover, it also shows that the PV system can be used at an inclination of 22° and only for plants at higher plants, as is demonstrated in a specific scenario.

Figure 3 exhibits the comparison of accuracy achieved by the various authors in the studies of Table 2 based on either AI or ML techniques. It is possible to observe that the results are not ordered over time and the variability of the results depends on the authors and the possible case studies, increasing the complexity of the efficiency of the overall analysis. It is confirmed that all the considered studies present higher accuracies than 75%, even reaching 97%.

Figure 4 shows the usage of AI, ML and deep learning model methods used by researchers in various years of the studied research works. This visualization provides a deeper insight into the use of technology based on the involvement of these models in power generation industries for forecasting and analysis purposes.

Figure 5 compares MPPT, ELM and ANN models according to different indicators, such as rate of output, RMSE, MSE and precision. Overall results show similarities between the techniques although ANN is superior in all the parameters compared to the other architectures, demonstrating the reliability of this ML technique. Different studies demonstrated that periods for assigning weights for ELM are notably lower than standard ANN training methods, causing variations in the achieved results in precision and RMSE.

2.4 Result Based Analysis

Table 3 summarizes the various research based on methods, their performance, the outcome and the significance of the work. Moreover, the PV system is an electric power system that supplies solar power through the grid and there are several methods have been used to conduct a PV system. Those are the MPPT, ANN model, ELM model, and SVM model, among others. Those models optimise the output of shaded PV arrays or un-shaded PV arrays under "static and dynamic weather conditions" [99]. PV system conducts sustainable energy sources in present history. PV penetration information is based on the long-term efficacy of different algorithms and shows better performance in forecasting accuracy. Moreover, these articles help to understand the future challenges of PV penetration.

Various models have been selected due to their applicability and novel trends in the current state of the art, e.g., ANN, SVM, ELM, MPPT, OPV, PSO-ELM3, MLP, MLA, and FCL. For this analysis, hybrid techniques and combinations of different methodologies are discarded. These techniques are shown in Fig. 6 according to the usage and implementation in the research papers considered for this study. ELM and MPPT are most widely used by researchers for forecasting the performance and accuracy of the models, due to easy implementation and reduced training periods, being PSO is the least implemented due to reduced accuracy compared to other architectures. The combination of PSO with other advanced techniques, e.g., SVM and wavelet transform, is widely applied in the current state of the art to increase the reliability of the analysis and increase the overall accuracy.

Figure 7 shows the accuracy of the models measured based on weather conditions. The considered researchers tested their models on static weather data and dynamic weather data, and based on both conditions, the forecasting accuracy was measured in each case. The MPPT, ELM, ANN, and ELM had higher accuracy but there is a slight difference for the different weather conditions. SVM achieved the best overall accuracy for forecasting and results with dynamic weather caused by its high suitability due to the implementation of different kernel functions, and high reliability in dimensional spaces and differentiated classes.

The average accuracy of MPPT, ELM, ANN and SVM is illustrated in Fig. 8. SVM and ANN performed with higher accuracy than MPPT and ELM, even reaching 98%. It is possible to confirm the conclusion obtained from Fig. 6, being that ANN and SVM provide better results due to advanced training periods.

Table 2 Summary of various studies based on method analysis

Journal citation	Methods	Advantages	Disadvantages	Performance
Mazur et al. 2017 [81]	Chromatographic methods have been used through ChromaTOF-HRT software	This study analyses the detection and identification of N, N-diethyl carbamodithioic acid methyl ester. Several interfering fragments are discussed in the Peak True spectrum, because of a closely eluting interfering compound.	This study has not had enough calculation and implementation of too many figures and less discussion.	All data is used for high-resolution Folded Flight Path multiple reflecting geometry time-of-flight mass spectrometer and Agilent 7890 A Gas Chromatograph. The formula is used for the presence of compounds with elemental compositions.
Michaels et al. 2020 [82]	The statistical and probability theory method has been imposed in the research by the programmer.	The device ML helps in the enabling of the IoT device to adapt to the changing environment. Therefore, the combination of ML and environment sensing helps its synergies.	The accuracy of the research is limited to 80% of standard images.	In the experiment set up 152 J or $4.41 \cdot 10^{20}$ were required to train for the verification of the ANN. The ambient harvesters provide a new generation of self-powered devices.
Yousuf et al. 2021 [83]	Both traditional and AI methods are used in this research.	The research helps to understand that the implementation of the automation of the power systems helps in the restoration, fault and network necessary.	The implementation of the AI helps in the automation of their process however, malfunctioning in the software might result in poor estimation.	The results of the research show that the FL, GA and ANN help in the improvement of operation and productivity.
Priyadarshi et al. 2020 [84]	The classical FLC and the ANN methods are used within the research.	The research helps to understand various artificial intelligence techniques that have been reviewed.	The major disadvantage of the FLC is that it has complex fuzzy rules, membership functions and requirements of the previous system knowledge.	The results of the research showed that the implementation of the FL-based AI techniques helps in the utilisation of maximum PV. ANFIS is considered to fit a combination of FLC and ANN.
Omran et al. 2021 [85]	A new intelligent and accurate method of detection of SAF in the PV systems.	In the research, the PSCAD model is used to generate the Arc Fault Model. The achieved accuracy in the proposed detection is 98.9%.	The implemented methods in this research face various limitations such as the interference of switching and having a lack of estimation.	The performance of the model shows the fact that the proposed detection method is 98.9% accurate. The evaluation of the performance and the proposed results are implemented using Python.
Abo-Sennah et al. 2021 [86]	The methods consist of seven MPPT methods such as P&O, incremental conductance (INC), FL controller (FLC), ANN, modified perturb and observe (M-P&O), ANFIS and cuckoo search.	The implementation of CS has the advantage of low implementation cost and fast computing.	The implementation of the method despite having low cost has some disadvantages. There are disadvantages regarding the oscillations around MPP.	The performance of the techniques shows the fact that the CS is the most effective technique of all.
Li et al. 2020 [87]	The method applied is the microelectronics technology helping in the enabling of the autonomous edge in the computer platforms.	The application of the technology helps in the reduction of cost and increases in the volume of manufacturing.	One of the negative effects of the crystallographic defects is the power decrease at high power density on PV at the heteroepitaxial materials.	From the research, it can be seen that the dist. Sized III-V PV cells grow in the SOI. The performance can help in large-scale manufacturing at low IoT costs.
Chen et al. 2020 [26]	The ternary cation halide-based perovskite switchable visual sensor is used.	It helps in the exhibition of the great potential of compact and smart vision for the autopiloting of vehicles in the future.	The high-fidelity imaging of PNN and it is in-sensor computing is restricted to the maximum enhanced accuracy of 263%.	The report shows the fact that the devices exhibit a responsivity over the range of 540 to 1270%.
Mellit et al. 2020 [88]	AI-based techniques such as ML and DL.	Improvement in the model accuracy during cloudy days.	Only one approach is focused on alternate approaches not considered.	ML methods have shown the potential better than other branches of learning for forecasting with the combination of optimal learning algorithms. Long-term PV power forecasting can be easily achieved using NWP models and DL including LSTM and CNN.

Table 2 (continued)

Journal citation	Methods	Advantages	Disadvantages	Performance
Simal Pérez et al. 2021 [89]	Calibration has been measured for standardization to find the loss percentage. The correlation methods have also been used in this study.	The use of different sensors in the plant and the use of the methods have helped in estimating the losses of soiling in the plant.	The PV system can only be used at an inclination of 22° and only for plants at higher plants.	Soiling losses were estimated in the first scenario by module temperature, irradiance on the array plane, ambient temperature and solar altitude. The nMBE was near to 0%, whereas nRMSE was less than 12%.
[24]	PV cell modelling which includes single-diode modelling, double-diode modelling and maximum power point. The adopted ML algorithm method is also used.	The models give the benefit of estimating the output power with accurate modelling of PV systems.	The use of configuration models sets a limitation on the accuracy of predicting the performance of PV systems.	The normalised mean absolute error up to 1.5% ensures an error less than obtained from both single-diode and double-diode with a reduction up to 0.15%.
Kurukuru et al. 2021 [90]	The flexible PSO ANN algorithm model and k-NN techniques have been used. Further, GRNN, PSO and ANN Fuzzy Inference Systems have been used.	Efficiently identifies the input data and does not affect the end solution due to intermediate failures. The applied methods also have the best performance after implementation.	The repetition in fitness function affects the time of processing and the methods can show wrong results if trapped in local optima. This method has slow speed processing.	ANN is the most used AI technique and depends on the case. Whereas, in optimisation, PSO and GA are used.
Garud et al. 2021 [91]	Applications of ANN, FL, GA and hybrid models are used for predicting solar radiation and design, modelling, installation, MPPT, fault detection and prediction of the performance of PV systems.	The used methods will help in the modelling and installation of PV systems.	The hybrid models have complexity associated with implementing the algorithms. Different methods do not work on real-time data and it works on past-recorded data.	Many meteorological stations were available for developed ANN, FL, GA and their hybrid models. The result shows ANN is the best tool for predicting solar radiation as compared to other AI techniques.
Ghadami et al. 2021 [92]	Data mining of electrical energy consumption, simulations of PV and motivation algorithms have been used.	These methods are beneficial for converting threats of solar harvesting into opportunities as per the novel urban organisations. Decision support system (DSS) can create energy demand.	Energy harvesting is a challenge in megacities, especially in developed countries.	ANN soft computing is said to be effective in forecasting the demand for electrical energy. It also helps in creating an online monitoring system with an accuracy of more than 99%.
Hussain et al. 2020 [93]	ANN structure has been used as a method. Further, ANN network training and validation have been used.	Two parameters can be activated and PV parameters such as V_{mpp} and I_{mpp} are not required. Another benefit of the proposed algorithm is that ambient temperature has not been included in the method, excluding temperature sensors	The sampling data cannot be taken as expandable to the other PV systems as there are very few commercial inverters that offer to extract these signals. It becomes one of the major disadvantages of the proposed system.	As per the research results, the performance of the ANN network structure has shown an accuracy between the range of 96.5–98.1% during normal operations and partial shading conditions.
Bouchouicha et al. 2020 [94]	MLR and ANN model with three types of neuron connection architectures that is FFNN, cascade-forward neural network (CNN) and Elman neural network	ANN can find the number of hidden layers which is a challenge for other models.	The MLR model is not able to find the hidden layers as effectively as the ANN model.	The second model of ANN gave the best result among other models with an average MAE of 6.37% and normalised RMSE of 9.55%.
Mahmoud et al. 2020 [95]	Day-ahead method, Newton Raphson, Gauss-Seidel methods, OpenDSS software and neural method.	The proposed methods apply to a large-scale unbalanced distribution system (the IEEE 906 Bus European LV Test Feeder) with a PV grid-connected unit. Test systems and datasets highlight the computational efficiency of the proposed methods.	The disadvantage of this study is that the performance of the NN model is not analysed deeply.	This study shows ML techniques, renewable energy sources, and the value of values of MSE, RMSE, MAE, mean absolute percentage error, and SSE.

Table 2 (continued)

Journal citation	Methods	Advantages	Disadvantages	Performance
Theocharides et al. 2020 [96]	PV forecasting method has been used.	A daily solar irradiance clustering analysis, network hyper-parameter tuning analysis and ANN model topologies along with several architectural parameters have been calculated through several metrics.	Other ML models are not described, requiring more details about the training and development of the algorithms.	The forecasting performance variability of the resulting optimal ANN day-ahead PV power production ensemble forecasting models.
Zhou et al. 2020 [97]	Multi-objective optimization model of the water-food-energy nexus, Multi-objective grasshopper optimization algorithm is used in this study.	This study analyses the improvement rates of hydropower output attained 6.8% and 6.5% in spring and summer accordingly and reached as much as 16.7% and 10.3% in autumn and winter accordingly.	Here is needed to analyse short-term complementary operations between floating PV and hydropower generation.	Several formulas are used to analyse floating PV and hydropower calculating Smin and Smax as the minimum and maximum reservoir storage (m3), respectively. Nmin h and Nmax h are the minimum and maximum hydropower output.
Chandra et al. 2020 [98]	MPPT methods are used on PV arrays. ANN and FL methods are used to implement MPPT applications.	ANN applications for MPPT improve the output power in the PV array and provide better results than optimization methods. Inductor current ripple, capacitor voltage ripple, and SEPIC efficiency to provide AI control technique.	There are need to analyse the future implementation of the solar water pumping system.	The trivial MPPT techniques show high ripples in current, voltage, power and torque in this study.

3 Overall Discussion

As it has been seen throughout this review, different AI techniques have been implemented for PV systems. Specifically, this work distinguishes five main fields: price prediction, operation, forecasting, costs and ML. After comparing the different methods used, it can be seen that the most commonly used are ANN, SVM, ELM, MPPT, OPV, PSO, MLP, MLA and FCL with different performances and accuracies [116]. Among all of them, SVM stands out with the best performance and accuracy across the different applications.

Different approaches for price prediction, e.g., loop, non-linear, and robust approaches, have been widely defined by several methods including time series analysis, time decomposition, STL, Holt-Winters, Bates and Granger, Aiolfi and Timmermann. LSTM is a relevant tool with high reliability for large data volumes. Different techniques have been proposed to combine LSTM with ML, DL or statistical tools, to enhance the performance of forecasting compared to basic LSTM. Another relevant methodology is FNN, due to high accuracy in the results although the main limitation is based on training requirements. This study also demonstrates that deep learning is very useful for recognising the pattern of generating PV energy. This review highlights the need for the use of AI techniques in the field of PV systems, as they improve the accuracy of previous methods by allowing the analysis of significantly larger amounts of data. In addition, ML is a breakthrough in analytical techniques as it can be applied to a range of cases in a generalised way. Operators can potentially overcome time series forecasting challenges through adept utilization of LSTM, offering an effective solution for PV generation amid current energy challenges. Different authors have combined solar irradiation predictors combining ML, statistical methods, single models, and AI approaches. In terms of analysis of costs, MPPT methods, e.g., incremental conductance method and disturbance observation method, were used to control the voltage level and restrain the current of the photovoltaic cells at the minimum value, and the actual conversion power was limited affecting the output power of the PV cells. It is concluded that solar energy is cost-effective for commercial purposes due to the reduction of the overall costs of electricity generation and consumption.

AI and ML are being widely used in electricity forecasting and PV generation domains. The primary objective of analyzed studies is to identify PV forecasting using MLP-based methods containing ANNs and statistical approaches. Global economic development continuously enhances the market demand for electricity resulting in generating a grievous environmental impact. Proposing a Ps-LSTM framework to control the fault of ML algorithms, which are applied only to a huge volume of information solar energy

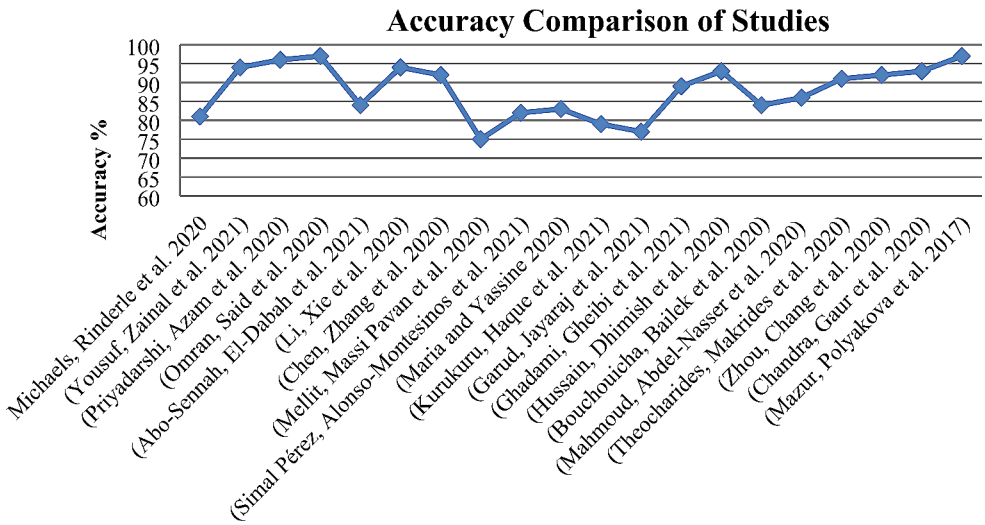

Fig. 3 Accuracy comparison of different studies between 2017–2022

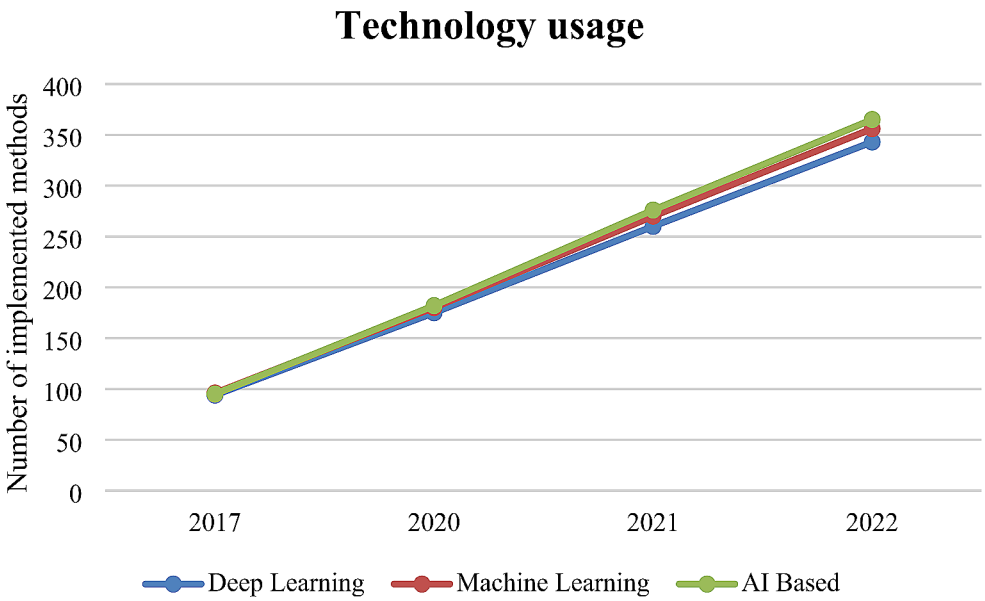

Fig. 4 Technology Usage of DL, ML and AI-based methods

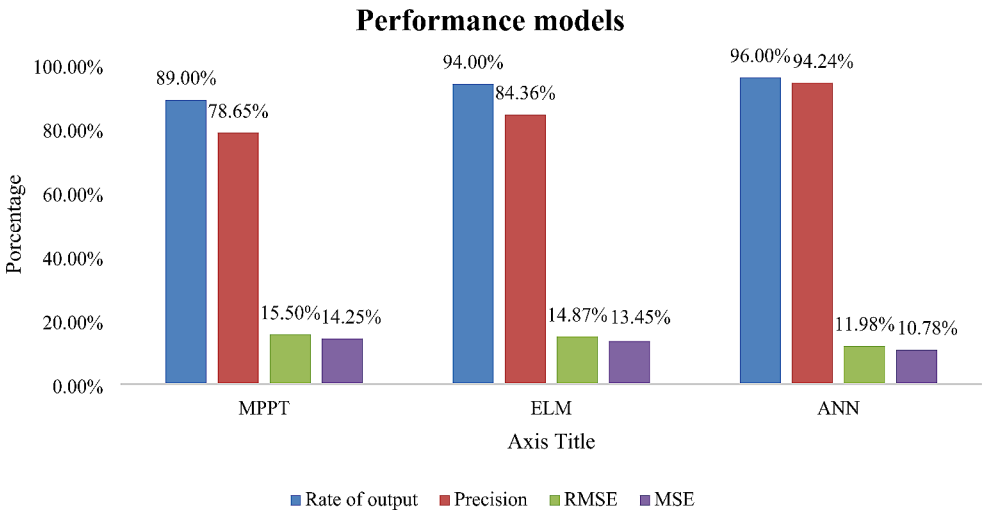

Fig. 5 Performance models for MPPT, ELM and ANN

Table 3 Summary of research based on result analysis

Journal citation	Methods	Performance	Results	Significance of the work
Olowu et al., 2018 [100]	Accurate estimation methods and forecasting methods have been used in this research.	Better performance of PV penetration has been seen in this research.	PV penetration has been increased with the help of seven big data characteristics in this research	After inspecting this research, readers will be able to understand the future challenge of PV penetration
Akhter et al., 2019 [101]	The research is a review of the metaheuristic and ML methods applicable for the forecasting of the PV power output.	The performance of the ARMA model is seen to outperform the ANN, SVM and ELM models in forecasting.	The results of the research showed that the hybrid techniques provided a better performance in forecasting.	The comparison of the metaheuristic and ML methods helped in the choice of forecasting techniques for future researchers.
Wang et al., 2020 [102]	There are four types of methods used. These are physical models, statistical methods, regression methods and hybrid methods to analyse AI and ML algorithms.	AI analyses "a certain degree of logical reasoning, which is helpful to realise a high level of intelligence for solar predictors".	Artificial intelligence methods, optimizers and prediction structures discussed PV power prediction and solar power forecasting structures.	This study shows that "AI algorithms have been widely applied in solar radiation and PV power prediction with attractive performance".
Al-Majidi et al., 2020 [103]	P&O algorithm, Fuzzy Logic Controller (FCL) method and ANN method are proposed methods in this study.	PV cells enhance the performance of the ANN model to predict the PV curve. These are used different formulas: $PV = IL - Id - Ish$ $IL = G\{IS[1 + ka(T - TSTC)]\}$	PV arrays are used to simulate with value 25 Ω. The solar G decreases from 1000 to 200 W/m2 at 1 to 2 s and then, it is increased from 200 to 1000 W/m^2 at 3 to 4 s, whilst the input T is kept constant at 25 ◦C.	Several algorithms improve the stability and reliability of PV generation.
Ağbulut et al., 2020 [104]	A modelling method for CPV system, the novel designed system, SVM, MLA and other ML methods	The value of R^2 value is near to 1. Therefore, it shows better performance of ML algorithms	MBE delivers information based on the long-term efficacy of algorithms.	The data of power output can be easily forecasted by people with four ML algorithms such as SVM, KNN, ANN and DL
Sharadga et al., 2020 [105]	Deep learning, statistical methods, power prediction methods, sparse Bayesian extreme learning machines, MLP and other persistent methods	The utilisation of ARIMA and SARIMA is more than 1, consuming more computational time than the predefined period.	The degree of integration of ARIMA and SARIMA models is set to 1.	Readers will be able to validate the significance of PV-generated models with the help of solar power forecasting results after inspecting this research study
Ammar et al., 2020 [106]	Backpropagation, hybrid optimization, least squares method and PV prediction method have been used in this research	The fluctuation of PV power may affect the performance of the water pumping system.	The Ghouard model is effective for the estimation of solar irradiation on sunny days. Moreover, Capderou topology is the best model for cloudy days	After reviewing this research study, readers will be capable of estimating weather data, solar irradiation, and ambient temperature. Moreover, the usage of a feed-forward neural network in estimating weather can be identified by people
Feng et al., 2020 [52]	The least square method (H + β T), circuit training method, the distance the weighting method and the ANN method	The performance of the model has been affected by the local culture. It shows the poor performance that affects the validity of this research.	Yinchuan station offers the best results of modelling whereas Xi'an station reveals the worst modelling results	Readers will be able to grasp the poor prediction of the SVM model. Besides, the usage of PSO-ELM3 can be easily understood by people after reviewing this study
Li et al., 2021 [25]	Pre-processing method, transformation method, ANN, DNN, hybrid and data-driven methods	ANN method mainly achieved more than 90% of accuracy. This research study used ANN for performance evolution, which indicates the better performance of the research study.	Results: TA = 33 ◦C, G = 380 W/ m^2 FDD accuracy = 97.4% ANN plays a vital role in properly detecting and diagnosis the PV fault	After reviewing this research study, readers will be able to analyze the application of ANN to detect the fault

Table 3 (continued)

Journal citation	Methods	Performance	Results	Significance of the work
Cortes et al. 2020 [107]	Artificial Intelligence method, parameter estimation method, fabrication method and analytical method	A hidden layer along with the smaller number of neurons is used to achieve better performance. The response of a network did not change after 900 training points, showing better performance than the other network.	As per the result section, regularisation is an effective option to improve the ability of the model and reduce the model's complexity	Readers will be able to understand the characteristics of a polycrystalline PV cell
Dass et al., 2020 [27]	Constant voltage method, hill-climbing method, open-circuit voltage method, incremental conductance method and short-circuit current method	The performance analysis of load current distortion and load voltage is discussed in this research, showing good performance.	The simulated PV system consists of a DC converter, MPPT controller and series-parallel solar panels.	This research paper is related to grid integration of the PV system. Therefore, based on this research, readers will be able to check the ability of the power quality conditioning system
Mellit et al., 2021 [108]	Manual methods, semi-automatic methods, the automatic methods.	It creates a positive impact in the long run.	DL and ML are two relevant artificial intelligence algorithms. ML employs mathematical algorithms that enable machines to learn on their own.	In terms of cost, complexity, software sustainability, and viability of real-time applications, this research presented the most widely used algorithms, e.g., machine AI for defect detection and diagnosis.
Zhang et al., 2021 [109]	PV prediction method, mathematical statistic method, emerging prediction method, artificial intelligence prediction method, neural prediction method,	According to the findings, the model suggested in this study has some consequences and benefits in predicting PV power generation.	-	The impact of numerous parameters on the forecasting of PV systems is investigated in this study, as well as the link between the various factors.
Meftahi et al., 2020 [110]	ML method, DFT method, variable selection method, descriptor method	Researchers illustrate how machine-learning techniques can use computationally expensive FT computations to quickly and accurately estimate crucial OPV materials parameters.	OPV materials are of specific importance due to their capability to produce inexpensive, printable semiconductor devices that transform photons into electrical activity.	OPV technologies offer opportunities for low-cost, reproducible solar cell materials. However, because there are so many potential donors and acceptors, choosing the ideal materials is difficult.
Ali et al., 2021 [111]	The traditional method, incremental method and MPPT method.	The simulation results are compared to certain standard tracking methods. The findings highlight their superiority in terms of tracking speed and output DC power, which improves the efficiency of solar systems.	This work is unique in that it combines the meta-heuristic optimization method alongside well techniques and algorithms to create a better monitoring system for harvesting the maximum amount of power from PV arrays.	This research focuses on increasing the monitoring of the MPP when atmospheric circumstances change, hence increasing PV efficiency. AI is being employed to develop a massive maximum power point tracking control system, rather than traditional methods of maximum power point tracking.
Bendary et al. 2021 [112]	Fault detection method, MPPT method	The loss of one of the solar modules is one of the most serious threats to the electrical power system's reliability and stability.	PV fault detection technologies are necessary to clear undesired defects to increase the dependability and efficiency of solar farms.	PV systems are commonly used and deployed in a variety of applications, including electric vehicles, residences, and satellites.
Murillo-Yarce et al. 2020 [113]	Statistical method, physical method, MPPT method	The control architectures under consideration are complex hybrid systems that mix traditional and modern methodologies, such as artificial intelligence and statistical models to create complex hybrid systems.	The functioning of PV electrical energy installation necessitates the use of complex control structures. This review is based on the most recent studies that have been published on controllers used in solar systems	This paper's key contribution is the creation of a generalised control framework and the identification of current trends. The key discoveries are summed up in the development of progressively robust controllers for increased efficiency, power quality, stability, safety, and economies in operation.

Table 3 (continued)

Journal citation	Methods	Performance	Results	Significance of the work
Navid et al., 2021 [6]	Fault monitoring method, electrical method.	The dispersed existence of PV facilities with millions of generators distributed over kilometres increases the probability of faults and related risks.	Various defect monitoring and diagnosis systems are currently in use, with electrical parameters being calculated.	Solar PV penetration into the global electricity supply network has recently increased. As the size and percentage of PV systems in the energy mix grows, so does the operational complexity and grid stability reliability.
Ahmad et al. 2019 [114]	MPPT methods such as Fractional short circuit current-based MPPT (FSCC) and fractional open circuit voltage-based MPPT (FOCV) are used in the study.	MPPT techniques are calculated by implementing several formulas.	This study showed that reasonable dynamic and steady tracking of MPP, analogue and digital implementations is possible with low complexity.	This study evaluates MPPT algorithms which may help the MPPT developers to pick a convenient technique for any desired PV system.
Liao et al., 2021 [115]	Innovative methods	This article presents a rapid and reliable approach for detecting solar cell problems using a UAV equipped with a thermal imager and a visible light camera.	A new concept of real-time monitoring and analysis of the health of PV panels is included. An imaging process is applied to detect the abnormality of solar modules. Grayscale conversion, filtration, and 3-D temperature representation, among others.	Solar energy has emerged as one of the most significant sustainable energy sources in current history. The monitoring and supervision of the health conditions of solar modules in a large solar farm become an essential issue with the quick and large-scale installation of solar farms.

production forecasting by using a deep learning approach. The survey literature has a strong concern over the finding of a data-driven approach in the technological and digitalised era. Under the context of the method, different methods of artificial and ML have been used [64]. Classification, optimizations, regressions and data structure exploration have been used as a method of artificial intelligence to reveal the impact of AI on the development of power electronic systems. XAI has been integrated into various studies over recent years. The analysis proposed in this study has presented different trends in the current state of the art, showing the main implementation conditions, challenges and constraints of different XAI techniques employed. It is demonstrated that XAI proposes potential improvements for the practical use of ML techniques, but obstacles such as standardization, security concerns, and unreliable confidence levels need careful consideration. Additionally, the analyzed papers explore potential applications and future research directions concerning XAI and energy, including smart grid applications, optimal energy management, energy consumer applications, and power system monitoring. The results indicate that SHAP and LIME represent the most widely utilized XAI techniques. Moreover, traditional ML algorithms are prevalent in XAI applications, whereas DL models are seldom integrated. Another relevant technique is the Physic Constrained-LSTM model, which helps in the superior performance of the prediction of the solar PV cells in the accuracy of forecasting the temperature. It is demonstrated that IME, XAI, and SHAP tools are widely used to acquire insight into solar PV power generation forecasting utilising explainable AI tools.

4 Conclusions and Future Research

Solar photovoltaic emerges as an alternative energy capable of meeting a greater percentage of global energy needs due to novel technical advances, reduced costs and high accuracy. The photovoltaic system is an electric power system that supplies solar power through the grid, being requires novel techniques for data analytics, forecasting and control. This paper presented a systematic review of several artificial intelligence and machine learning algorithms to present the main challenges and limitations of the current state of the art. Several researchers are still working in this domain to improve the accuracy and precision of the forecasting models to enhance the competitiveness of photovoltaic solar energy. This study presents a review of recent advancements in the technologies, techniques and methods widely implemented following three different methodologies: review-based, method-based and result-based.

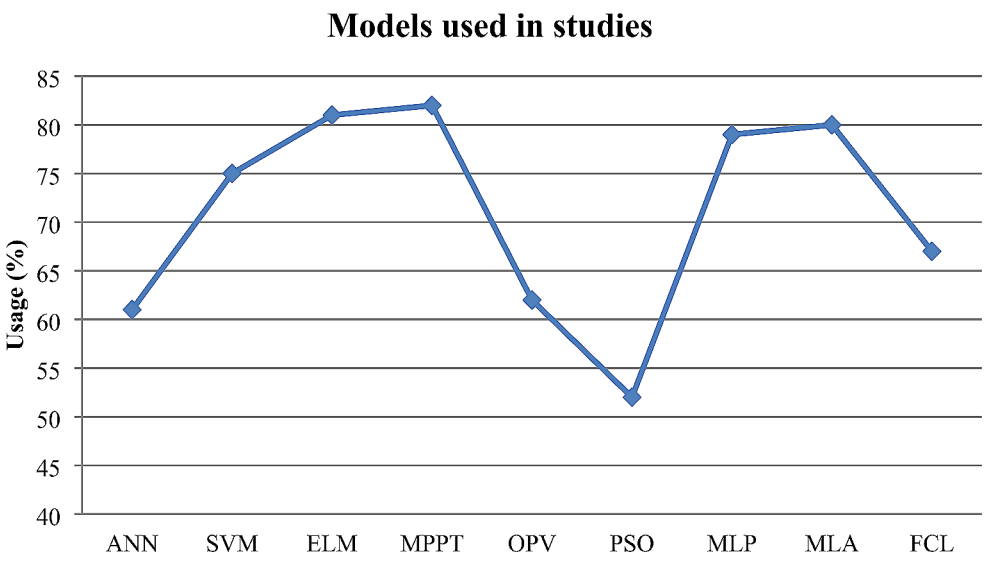

Fig. 6 Models used in studies

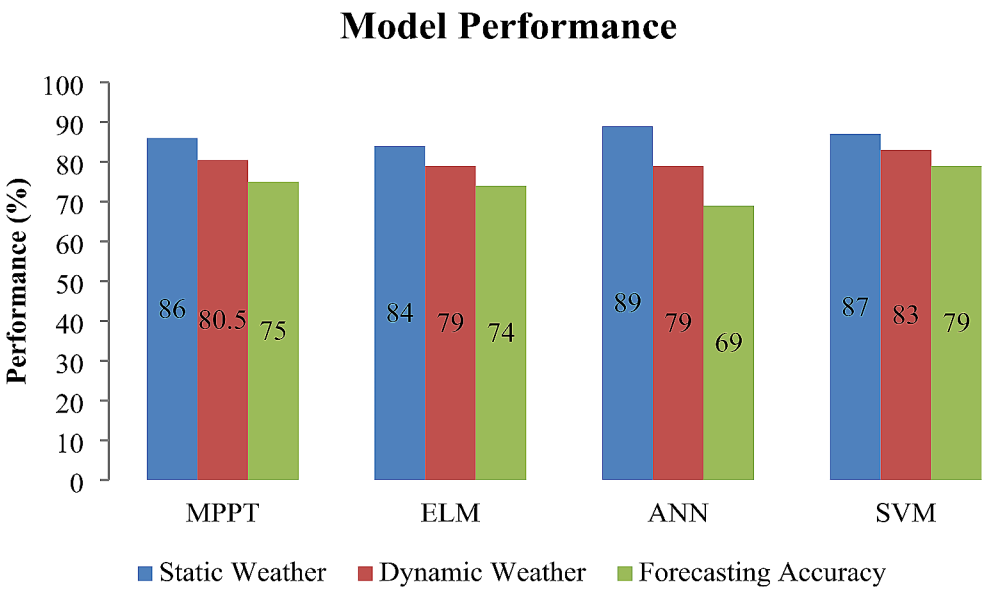

Fig. 7 Model performance on weather conditions

The comparison of the power production using the different PV cells is understood with the help of the review of the research papers in the assignment. The Physic Constrained-Long Short-Term Memory model helps in the superior performance of the prediction of the solar PV cells in the accuracy of forecasting the temperature. It is also seen that extreme learning machines and k-means have shown accuracies of around 90%. Artificial intelligence methods are demonstrating their high strength and reliability compared to conventional modelling models, with reduced computational costs and providing reliable solutions. In most of the research studies, multi-objective optimisation methods, multiple linear regressions and artificial neural network methods have been used to observe the rate of output and verify the computational efficiency of the proposed method. There are several methods have been used to conduct a photovoltaic system, e.g., Maximum Power Point Tracking, Artificial Neural Network model, Extreme Learning Machine, and Support Vector Machine, among others models. Different basic approaches, e.g., Particle Swarm Optimization or several optimization techniques, presented low accuracy compared with other Machine Learning techniques, being less implemented in the current state of the art and being necessary the combination with other advanced techniques. It is important to highlight that the Support Vector Machine is one of the most applied techniques providing high reliability and suitability in different real case studies. It is also concluded that Machine Learning-based methods have recently become relevant in the analyzed literature caused of the increased complexity of operational scenarios for solar plants together with high computational power and data availability. In future research, it is proposed the analysis of novel hybrid methods to be compared with basic

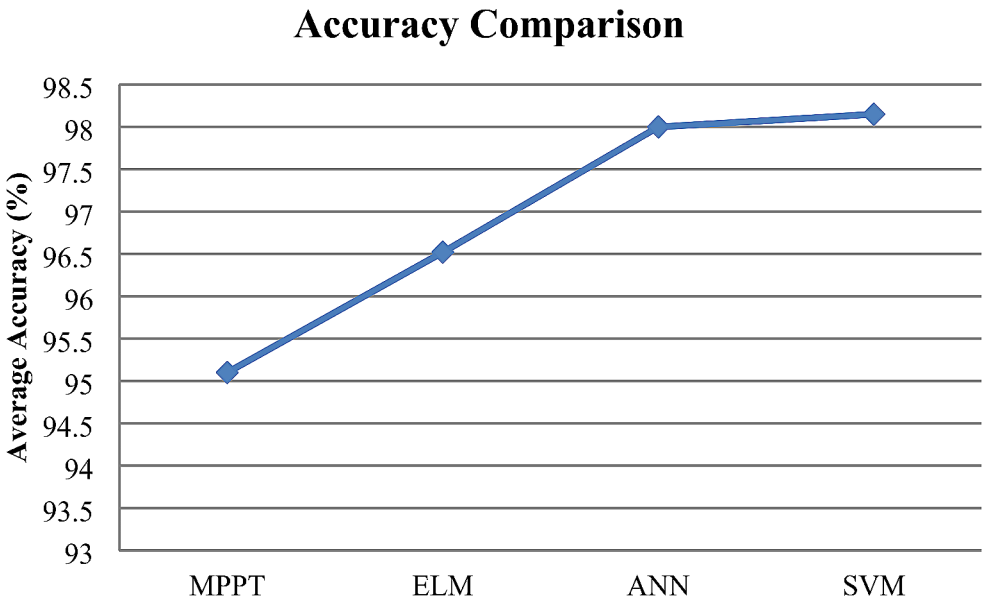

Fig. 8 Model accuracy comparison

Machine Learning techniques, together with novel working scenarios with large solar plants.

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