Artificial Intelligence Application in Renewable Energy Sources

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Abstract

The study employs artificial intelligence algorithms, machine learning, genetic algorithm, and hybrid algorithm for the optimization of renewable energy sources. The Kaggle platform was utilized to test the performance of each algorithm under identical conditions. To enhance algorithm accuracy, training conditions (latitude, longitude, and panel area) were specified, allowing sufficient time for training. This modification contributed to improving the model's sensitivity to weather conditions and its ability to choose the best solution path. The research findings indicated that for solar panels, the genetic algorithm is the most effective. Therefore, its implementation should be considered in further development within Ukraine's energy sector.

Keywords

Renewable energy sources, algorithms, machine learning, genetic algorithm, hybrid algorithm, optimization, Ukraine.

1. Introduction

Modern challenges such as environmental issues, the depletion of traditional energy sources, and economic factors contribute to the increasing demand for energy from renewable sources. However, expanding the use of alternative power plants is complicated by significant investment requirements, limitations on suitable geographical locations, and risks associated with climate change and natural phenomena.

The utilization of artificial intelligence and "smart" algorithms can serve as an innovative solution to these problems, enabling effective management and optimization of energy systems while considering numerous influencing factors. This will facilitate the creation of a more resilient and reliable energy grid across various potential development scenarios, allowing for the balancing of supply and demand and responsive adaptation to changing conditions.

2. Task statement

Renewable energy sources (RES) are energy sources that harness natural processes continually replenished on Earth [1]. They include solar, wind, hydroelectric, biomass, and geothermal energy. The utilization of RES helps reduce dependency on coal, oil, and gas, while also decreasing carbon emissions and other harmful substances, fostering a more sustainable and environmentally friendly energy sector.

Artificial Intelligence (AI) is a branch of computer science concerned with creating systems capable of performing tasks that typically require human understanding [2]. These systems can learn, adapt, and make decisions based on collected data. AI is utilized across various fields, including medicine, finance, technology, and business.

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Its role encompasses analyzing large datasets, forecasting, process automation, system optimization, and decision-making based on complex algorithms. In the energy sector, AI can be employed for predicting and optimizing energy production and consumption, supporting distribution networks, as well as for the development of new technologies and energy-efficient solutions. AI can help ensure more efficient utilization of energy resources and contribute to the development of a sustainable energy sector.

Figure 1 illustrates that the demand for renewable energy sources, such as wind and solar, is increasing [3].

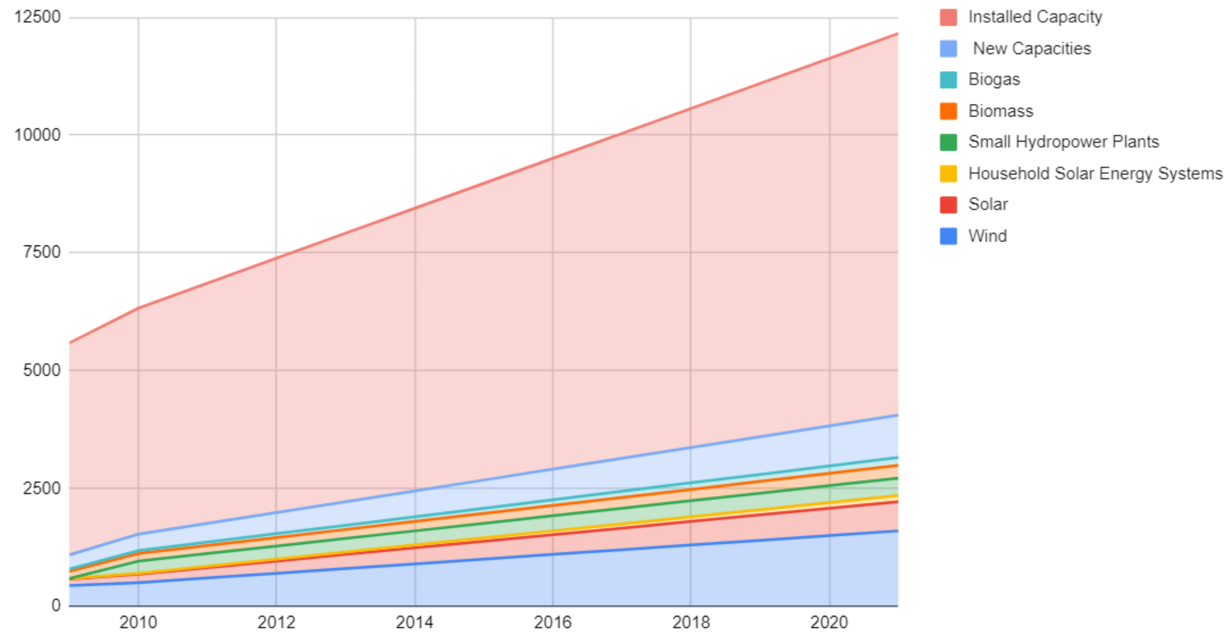

Figure 1: Demand for renewable energy sources [3]

In the case of solar radiation, there is a vast amount of available data on solar irradiance measured at the surface over short time intervals, which need to be mathematically transformed and processed to find the solar radiation reaching the Earth's surface at any given moment. There are various methodologies, but the most intelligent and flexible approach involves creating a system from scratch that utilizes this data to maximize the productivity of solar installations. This is precisely the kind of program that can benefit from the application of artificial intelligence. If programmed to analyze meteorological data and make the right decisions on how to deal with fluctuations in solar radiation, it can increase the efficiency and profitability of solar projects. Existing methodologies may offer an acceptable return on investment or useful production volume indicators, but in such a new field as solar energy, there often aren't reliable market data for comparison.

Statistical data indicate that there are growing trends in the development of solar and wind energy generation worldwide (Figures 2-3).

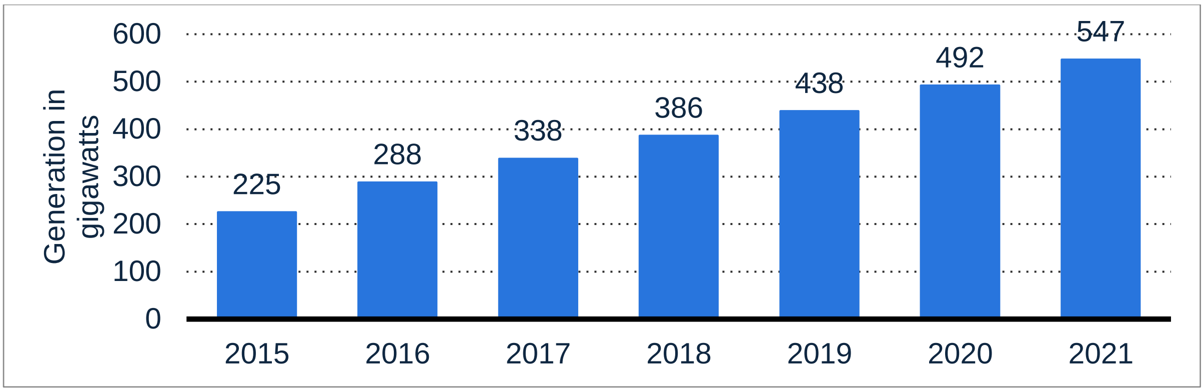

Figure 2: Generation of solar PV power worldwide between 2015 and 2021 (in gigawatts) [4]

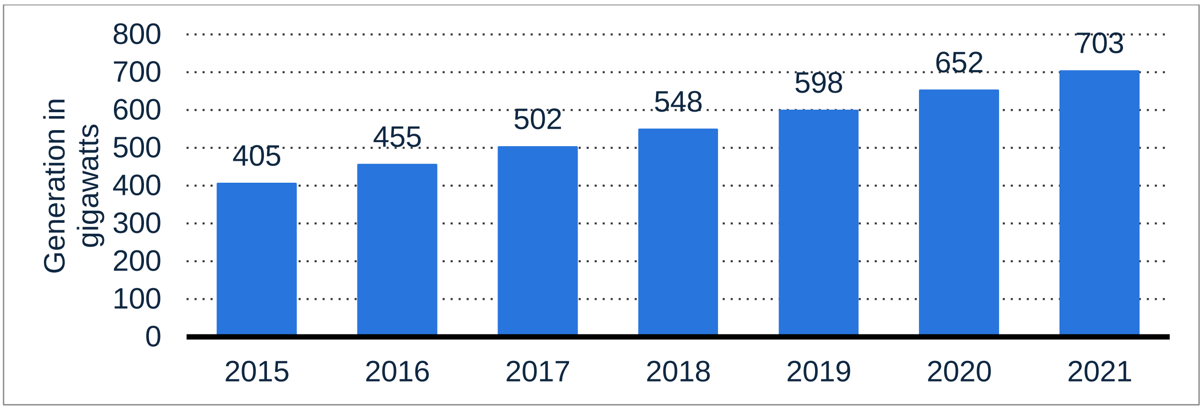

Figure 3: Generation of onshore wind power worldwide between 2015 and 2021 (in gigawatts) [5]

At the same time, the implementation of artificial intelligence into projects will enable maintaining a balance between electricity production and consumption, ensuring efficient management of electrical grids, and reducing inefficiencies. This will decrease reliance on traditional energy sources and lower greenhouse gas emissions [6]. AI algorithms can be utilized for forecasting and optimizing energy networks that supply electricity, allowing for increased efficiency in their utilization. Moreover, their application can help identify complex patterns and dependencies in production processes, facilitating the discovery of additional opportunities for enhancing energy efficiency.

Forecasting weather conditions using AI plays a crucial role in optimizing the utilization of renewable energy sources such as solar and wind energy. The application of AI can analyze large volumes of weather data, including temperature, humidity, wind speed, and so on, and forecast them for future hours, days, or even weeks with high accuracy. This plays an important role in improving the optimization of renewable energy utilization.

The application of AI in weather forecasting allows for the optimization of renewable energy systems by adapting them to predicted conditions [7]. For example, solar panel systems can adjust their positioning to maximize the collection of solar energy depending on expected cloud cover or solar radiation intensity. Similarly, wind turbines can optimize their operation, taking into account anticipated changes in wind conditions.

Thanks to accurate weather forecasts provided by AI, it's possible to efficiently plan the operation of renewable energy systems in advance, minimizing losses due to unforeseen changes in weather conditions. This helps increase the utilization of renewable energy sources, reducing reliance on traditional sources such as coal or oil, and contributes to a more stable and environmentally friendly energy future.

There are many algorithms utilizing AI. Therefore, an important task is to analyze and choose the best one for the utilization of renewable energy sources.

3. The choice justification of the AI algorithm using solar energy as an example

Machine learning algorithms are one of the most significant applications in monitoring and diagnosing various equipment. They can predict failures or errors using sensors of renewable energy equipment, such as pressure, airflow, temperature, etc., to detect patterns preceding failures or malfunctions. This enables proactive troubleshooting and prevents emergencies. Similarly, diagnosing patient illnesses allows for identifying factors that may worsen a patient's condition and predicting potential consequences of the disease. Optimizing individual processes allows for optimizing a particular process that stands out for its inefficiency by making changes to others.

Machine learning has also gained significant traction for weather forecasting. The choice of this algorithm was driven by its ability to analyze large volumes of data, which would be challenging for a group of humans to process. It can discover complex relationships between various factors, adaptability to new input data, and changes in decisions, and modelling of complex systems, allowing for finding the best connections between different factors to create an optimal model for solving the task.

A machine learning algorithm is a tool utilized for data analysis and automatic learning of complex relationships, enabling the resolution of various tasks from classification to prediction, providing broad capabilities. The algorithm consists of the following points:

Step 1. Data Collection – Initially, weather data such as temperature, air humidity, pressure, wind speed and direction, precipitation, etc., are gathered. These data can be obtained from meteorological stations, satellite images, radars, and other sources. Data Preparation - The collected data undergoes processing, including cleansing from anomalies, normalization, and possibly removing redundant features.

Step 2. Model Selection – Choosing a machine learning model, typically a neural network. Various architectures with different numbers of layers and neurons are considered during the selection process.

Step 3. Model Training – The model is trained on weather data from the database so that it can determine the relationships between weather variables.

Step 4. Model Validation – The model is tested on unseen data, which were not used during training, to evaluate its accuracy and effectiveness.

Step 5. Final Product (Weather Forecasting) – After successful training and validation, the model can be utilized for forecasting future weather conditions, continuing its learning process.

The advantages of this algorithm include high accuracy and adaptability. High accuracy indicates that machine learning can identify complex dependencies between different parameters, allowing for precise results. Adaptability means that the model can automatically adjust to new input data and produce corresponding results.

However, there are certain drawbacks to the algorithm, namely: dependency on data quality, complexity, and training speed. Dependency on data quality refers to the fact that the quality and quantity of data greatly influence the accuracy of the algorithm. Complexity in developing and maintaining the model can be challenging and may require significant computational resources. Training speed directly depends on the quality of algorithm implementation, data input quality, amount of input data, and machine performance on which it is executed. Training can take several days or even weeks.

For solar panels, machine learning might not be the optimal solution because it only predicts changes that will occur in the future. In this case, it's better to use genetic algorithms, which form the best model to make decisions based on events happening in real-time for the most efficient operation. The choice of this algorithm is also supported by its ability to optimize and mutate, finding non-trivial solutions to problems.

Genetic algorithms are an effective approach to optimization, modeling the process of evolution to find the best solutions. By simulating natural selection and genetic reproduction, they create populations of solutions that adapt and improve with each generation. This algorithm effectively solves optimization tasks in various fields, including solar panel placement, scheduling problems, and addressing complex optimization challenges. To operate the algorithm, an initial group of candidates with certain information and actions over it needs to be created. Following this, a cost (selection) function is established to evaluate the quality of each solution and select the candidate that will be the basis for the evolution of the next generation. For evolution to occur, selection methods need to be developed - principles according to which generations are crossed and mutated to achieve results. Finally, crossover and mutation operators are employed, responsible for genetic transition between generations and mutations.

The advantages of the algorithm include its ability to optimize complex problems with large spatial complexity. It offers flexibility and versatility in application to various types of tasks. Additionally, it can find the best solutions even in cases of constraints and incomplete information.

The drawbacks include high computational resource costs, especially when dealing with large volumes of data. It does not guarantee finding the optimal solution but rather the probability of approximating it. Selecting parameters such as population size, mutation probability, and crossover can be challenging tasks, and the choice of parameters directly depends on the quality and speed of learning. Inefficiency in cases of nonlinear, nondifferentiable, or discrete cost functions.

In wind farms, both machine learning and genetic algorithms are good choices, but one of the most effective algorithms for this purpose would be a hybrid algorithm. With its help, different algorithms and methods can be combined, allowing the creation of a ready-made product capable of performing tasks of different types, from equipment diagnostics to forecasting profits and expenses for a certain period ahead.

Let's delve into the hybrid algorithm, which combines various methods or approaches to solve a specific task. This could involve a combination of different algorithms, approaches, or even different technologies. To create such an algorithm, it is necessary to first determine the objectives for which it will be used, and based on this, combine the advantages of different methods to achieve the best result. Subsequently, an analysis is conducted on how compatible the components we have combined are. Some methods may be more compatible with each other than others, providing better optimization of the method and less burden for machine learning. Developing integration, or interaction between components, is the most challenging part because it requires connecting all algorithms and methods into a single system, ensuring data exchange between them, and coordinating their operation based on the results of each block. Now, the simplest yet crucial aspect of development is testing, where known tasks are inputted into the algorithm to ensure it functions as expected. In the worst case, parameter tuning may be required for optimal performance. Evaluation of results involves feeding data into the algorithm and comparing the performance with the desired method. Results are assessed, and it is determined whether additional optimization of your algorithm is needed or the possibility of adding new components for further performance improvement is considered.

Creating a hybrid algorithm is an iterative process that may require several attempts and modifications before achieving satisfactory results. It is important to be open to experimentation and prepared for changes during development.

The advantages of such an algorithm include improved productivity, resulting in better outcomes compared to using individual methods. Adaptability enables adjustment to various conditions and tasks, making them versatile. The potential for scalability - by combining different methods, hybrid algorithms can be more flexible and expandable.

The problem of calculating the volume of air pollution by motor vehicles is considered in [8,9].

The drawbacks include complexity in implementation, the need for a large number of resources, and parameter tuning. When constructing the algorithm, the number of combinations is very large, and within this set, the best to be found, even with the best optimization, the computational resource requirement can be significant. Parameter tuning is not straightforward because changing one parameter alters the entire sequence of actions, and we need to find the best parameters for each of the methods. All these factors need to be considered when selecting a hybrid algorithm for a specific task. It can be a powerful tool in solving complex problems, but it requires careful planning and tuning. Functioning of Information Web Resources for Services on Ecological Expertise shown in [10].

Let's consider the use of the algorithms mentioned above in the context of solar energy, specifically for solar panels in Zaporizhzhia city. For machine learning training, data such as temperature, latitude, longitude of the location of the solar panels, and predefined dependencies of efficiency on the angle of incidence of solar radiation on the panels were taken. The data were obtained from meteorological websites such as “Meteopost” [11] and “Sinoptik” [12] , which are shown in Figure 4.

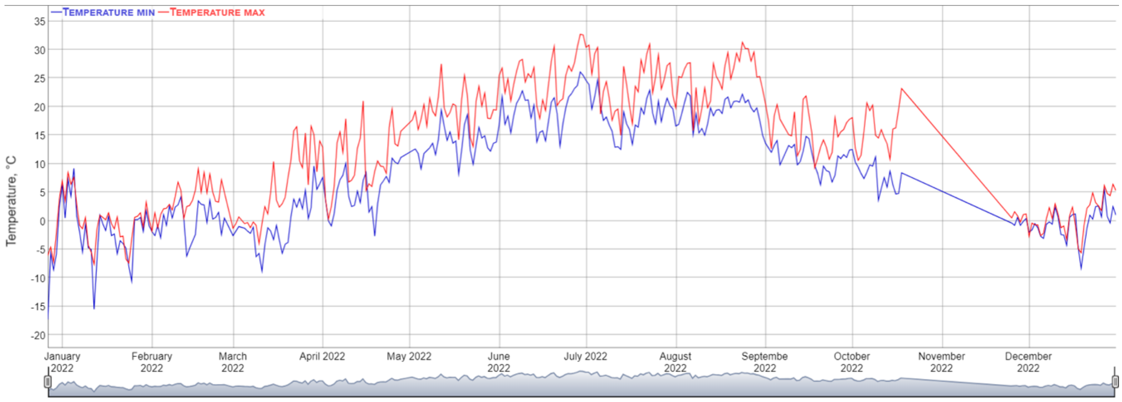

Figure 4: Graph depicting the air temperature trend in Zaporizhzhia city throughout the year 2022

For the angle of inclination, dependencies were introduced such as the optimal inclination angle for solar panels being the angle at which sunlight rays fall perpendicular to the panel surface. The smaller the angle of inclination of the solar panels relative to the solar rays, the more efficient the collection of solar energy. However, with a too shallow angle of inclination, the rays will reflect off the panel [13]. Latitude and longitude are specified during training for faster learning and more accurate results (Table 1).

Table 1
Determination of the inclination angle depending on the latitude of the location

Latitude of Location	Inclination Angle
0-15 °C	15 °C
12-25 °C	Equal to latitude
25-30 °C	+/- 5 °C from latitude
30-35 °C	+/- 10 °C from latitude
35-40 °C	+/- 15 °C from latitude
Above 40 °C	+/- 20 °C from latitude

Each algorithm was trained on identical data. After training, research was conducted on the efficiency (1) and average energy output (2) they were able to extract:

$$\eta = \frac{W}{sinh} \cdot 100\%, \quad (1)$$

where η - efficiency;
W – generated electrical energy;
$sinh$ – incoming solar radiation.

$$E = S \cdot \eta \cdot Q \cdot t, \quad (2)$$

where E – average energy output;
S – panel area;
t – operating time.

The research was conducted on the Kaggle platform using empirical data, where the panel area was 12.5 m^2. The obtained results are presented in Table 2.

Table 2
Research Results

	Machine Learning Algorithm	Genetic Algorithm	Hybrid Algorithm
Efficiency	92%	90%	91%
Average energy output	85 kWh	89 kWh	87 kWh

As seen from Table 2, the best result with the highest energy output at an acceptable efficiency was obtained using the genetic algorithm.

As a result of the analysis, a decision tree (Figure 5) has been created.

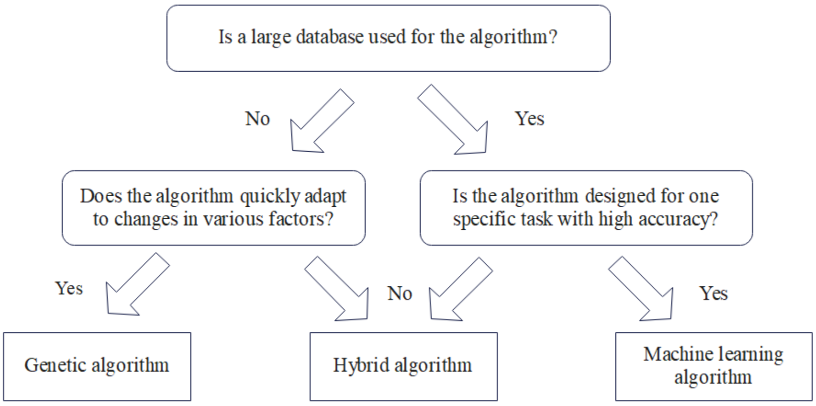

Figure 5: Algorithm tree

During its creation, global differences between algorithms, learning methods, principles, and the data required for their effective operation were considered. It was determined that there are no clear boundaries for the hybrid algorithm that distinguish it from other algorithms. However, during test studies, the algorithm was unable to replace other algorithms in their main directions. Therefore, in the decision tree, two branches lead to the use of the hybrid algorithm. The main questions were raised regarding the main advantages and disadvantages of the algorithms.

Analyzing the results obtained for training AI algorithms for solar panels, we can confirm that hybrid and genetic algorithms have shown themselves to be the most effective in terms of output energy. This is supported not only by the need for a small database but also by their ability to adapt to various changes.

4. Conclusions

Given the increasing demand for energy and the use of renewable energy sources, there is a growing need for advanced power plants. However, these tasks are complicated by huge investments and risks associated with climate change. The application of artificial intelligence can address these issues and help manage and optimize energy systems. AI takes into account various factors such as electricity demand and the availability of renewable energy sources, helping to create a stable and reliable energy network. However, the question arises as to which algorithm AI can provide the best solutions. The choice of algorithm depends on several factors such as task complexity, algorithm accuracy, available computational resources, and many others. For solar energy, the genetic algorithm can be considered the best choice, as it yielded the highest average energy output is 89 kWh. This algorithm is one of the few that can adjust in real-time to changes in various factors without reducing the efficiency of renewable energy sources.

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