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Application of artificial intelligence (AI) in wind energy system with a case study

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Abstract. Renewable energy is the fastest growing source of clean energy worldwide. The employment of wind energy is expected to increase dramatically over the next few years. There is a good source of wind power on the highways due to the movement of vehicles. A small windmill could utilize the wind power generated by passing vehicles and produce electricity that can power the lights on the highway. This paper presents the application of artificial intelligence to predict the current output from a small windmill placed on the highway. The results show a good concurrence between the experimental and predicted values.

Introduction

The main energy source is from fossil fuels, which is extensively used to meet the demand. The usage of fossil fuels directly harms the clean environment and also leads to global warming. Fossil fuels are non-renewable and get depleting, which makes people to focus on renewable energy sources. All over the world harnessing of solar and wind as a sustainable source of energy gained popularity to curtail the heavy dependency on fossil fuels and also to counter the global warming. When wind energy is used to produce electricity, less pollution from conventional power plants will be released into the environment. The need of concentrating on renewable energy resources has increased, particularly in the wake of the Gulf of Mexico oil leak and the Japanese nuclear accident. The installed wind energy capacity reached 196,630 MW globally in 2010, with 37,642 MW added in that year, according to the World Energy Association's report on wind energy for 2010. Enhancing wind farm design and layout; boosting wind turbine accessibility, dependability, and efficiency; streamlining the upkeep, assembly, and installation of offshore and onshore turbines and their substructures; showcasing massive wind turbine prototypes and expansive, interconnected wind farms, etc. are the main research areas that should be prioritized in the wind energy industry [1]. The first wind-powered generator was invented by Charles F. Brush, an electrical pioneer from America, and it produced energy in his backyard. He built a windmill that was 40 tons in weight and stood 60 feet tall. The actual wind mill measured 56 feet in diameter. The wind mill had a total of 144 separate blades. 500 revolutions per minute was the turbine's peak rotational speed. Everything in his basement was wired up to 408 batteries. With this technology, he was able to power his entire house, including the lab. Up until 1909, his wind mill operated for 20 years [2].

The wind turbine's size is determined by its intended use. Typically, tiny turbines have a power output between 20 and 100 kW. The 20- to 500-watt "micro" turbines are smaller and have a wider range of uses, including the charging of sailboat and recreational vehicle batteries. Water pumping is one use for turbines ranging from one to ten kW. Grain mills and water pumps have been powered by wind for millennia. While mechanical windmills remain a cost-effective and practical choice for water pumping in wind-free regions, farmers and ranchers are discovering that wind-electric pumping offers greater versatility and doubles the volume of water pumped for the same initial outlay. Furthermore, mechanical windmills have to be positioned straight above the well, which could not maximize the wind resources that are available. Electric cables can be used to link wind-electric pumping systems to the pump motor, which can be installed where the best wind resource is available. Depending on how much power you wish to create, household turbines can range in size from 400 watts to 100 kW (100 kW for extremely big loads). An average household consumes around 10,000 kWh (kilowatt-hours) of power year, or 830 kWh each month. To significantly meet this requirement, a wind turbine with a rating of between 5 and 15 kW would be needed, depending on the typical wind speed in the region. If the average yearly wind speed in the area is 14 miles per hour (6.26 meters per second), a 1.5 kW wind turbine can supply the energy needed for a house that uses 300 kWh per month. Automatic overspeed-governing mechanisms are included in most turbines, which prevent the rotor from spinning uncontrollably in extremely strong winds [3].

Harrous and Ahshan [4], [5] developed a hybrid solar/wind system for his home. The hybrid system consists of Bergey XL-1, a 1000-watt wind generator mounted on a tower 104 feet tall along with 300 watts of solar, which is a stand-alone system with batteries. The battery bank is a 220-amp system made up of eight 6-volt batteries wired as a 24-volt system. The system runs incandescent lights and a well pump at the barn, as well as water through heaters. The cost of the complete system was around $ 10,000 including equipment, trenching for wires, building permit, etc. For wind energy uses, there must be open space or accessible coastlines for wind energy plants. Saudi Arabia is a large nation with extensive coastlines and open spaces. In the majority of these locations, the wind speed is sufficiently high to make using wind energy cost-effective. Saudi Arabian authorities will invest billions in this potential field of electricity since they understand the value of renewable energy, particularly wind energy. Despite its vast oil reserves, Saudi Arabia is very interested in actively participating in the development of new technologies for the exploitation and use of renewable energy sources. Despite Saudi Arabia's substantial wind resource potential, there are several obstacles to its development. These comprise the resource's erratic nature, its seasonal and diurnal fluctuations, its isolated geographic position, and the electrical grid infrastructure required to transfer wind energy to load regions. Significant technological obstacles must be overcome in order to fully utilize Saudi Arabia's wind potential. The energy balance between the needed load and the generated power, as well as the matching of the wind turbine and location with an appropriate economic position, remain a significant problem. By matching the locations and wind turbines, the researcher created an extensive computer program that does all the calculations and optimization needed to precisely build the Saudi Arabian wind energy system [6].

Eltamaly et al [7] built and examined the dynamic performance of a novel wind turbine producing system using a thyristor inverter. The system is basically based on shaft generators, which are highly reliable and produce high-quality power output and are frequently employed in big ships. It was looked into if this innovative method could provide low-distortion electric power at a steady frequency even when the natural wind's velocity fluctuated. Additionally, a dynamic model was created, and it was discovered to have good agreement with the system's experimental and simulated results. Zemamou et al [8] investigated the remarkable performance of savonius wind turbines and how they might be used as an alternative to normal wind turbines to extract valuable energy from air streams. Some benefits of employing this kind of machine include its straightforward design, high starting and full operation moment, ability to receive wind from any direction, minimal noise and angular velocity when operating, and reduced wear on moving components. There have been many suggested modifications for this gadget over time. Another benefit of employing such a machine is the range of possible rotor designs. The performance of a Savonius rotor is impacted by each configuration. The performance of a Savonius rotor is influenced by air flow, geometric, and operational factors. For the majority of settings, the quoted range for the highest averaged power coefficient is between 0.05 and 0.30. The usage of stators has also been shown to result in performance increases of up to 50% for the tip speed ratio of the highest averaged power coefficient.

Renewable energy technologies affect how household power demands are met. Since most of the energy produced by fossil fuels is used in buildings and their unchecked use is linked to environmental risks, global warming, and the possibility of their depletion, it will be advantageous to replace the conventional energy generation system with renewable energy sources [9]. Globally, there is a growing need to transition from fossil fuels to renewable energy sources. The main causes of this transformation are the lack of fossil fuels and their detrimental consequences on the environment, particularly the climate. As a result, interest in renewable energy sources such as solar, wind, and wave energy is growing around the world [10]. Converters for multiphase generators, back-to-back linked converters, passive generator-side converters, and converters without an intermediary dc-link for high-power wind energy conversion systems (WECS) are all included in the low and medium voltage category. The series/parallel connection of wind turbine ac/dc output terminals and high voltage ac/dc gearbox are taken into consideration while evaluating the onshore and offshore wind farm layouts [11].

Artificial Intelligence (AI) in Wind Energy Systems

The majority of wind farms are situated in isolated areas or several miles offshore, thus it is vital to monitor their mechanical parts for maintenance in order to keep them from breaking down mechanically and perhaps cutting themselves off from the electricity grid [12]. Machine learning algorithms, particularly artificial neural network ANNs, are commonly used to process gathered data. The ANN's structure is inspired by real neurons, with basic processing units coupled by weighted linkages. It contains three major layers: input, concealed, and output. Furthermore, the number of hidden layers may be increased to construct the deep neural network (DNN) architecture [13]. The Artificial Neural Network (ANN), Backpropagation Neural Network (BPNN), Adaptive Neuro-Fuzzy Inference System (ANFIS), and Genetic Algorithm (GA) are some of the most often used and proven AI approaches. The level of technology today and potentially uses tried-and-true methods to create AI-powered renewable energy systems, particularly solar energy systems. To ascertain the state and progress of AI approaches in the field of renewable energy systems (RES), particularly solar power systems, a number of peer-reviewed journal publications were analyzed [14].

The physical methods forecast wind energy using meteorological data, such as topography, atmospheric pressure, and ambient temperature; the hybrid methods combine the advantages of multiple single forecasting models to obtain the final prediction results through various weighting strategies; and the intelligent methods process and optimize the integration of external and internal big data to estimate future wind energy. The statistical approaches anticipate wind energy time series by an assessment of the probability distribution and random process of the samples. Since intelligent approaches and AI-based hybrid methods are more efficient at analyzing the complex connections present in huge data sets, they are essential for increasing energy efficiency, decreasing energy usage, and allowing real-time decision-making in the wind energy business. [15].

Case Study

A small wind mill was fabricated using wind turbine mounted inside the tube, generator and a battery pack. The fabricated tubular wind mill was flexible and can withstand turbulence. The turbine inside the tube rotates in the direction of wind turbulence. Standard generator system was used which can deliver a power output of 1 kW along with a maintenance free battery pack, inverter and charge controller. Figure 1 shows the schematic diagram of the wind mill. Experimental data was recorded by keeping the wind mill on road side platform based on vehicular movements for 7 days. Duration of data recording on each day varies from 30 to 180 min.

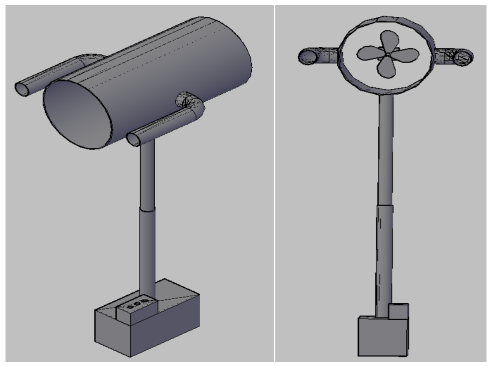

Fig 1. Schematic Diagram of Wind Mill

Artificial Neural Networks (ANN) use genetic algorithms that make use of adaptive heuristic search methods. A genetic algorithm is a better method for achieving the global optimum's convergence. Chromosome initialization is the first step in the genetic algorithm's operation, after which fitness is assessed using an objective function [16]. Chromosomes are genetically propagated by first selecting the most fit individuals and then using operators such as crossover and mutation. A multi-objective solution from the optimization toolkit and a genetic algorithm were used to optimize the process output variable models [17]. Ten neurons or nodes made up the hidden layer, the output current serving as the dependent output neuron, and time and wind speed serving as independent input variables were used to create the ANN network model [18]. Ten neurons made up the hidden layer of the neural network, which was trained until the mean squared error between the target and model output was as little as possible. The comparison between the goal values of the present output and the output values of the ANN network model is displayed in Figure 2 [19]. A high correlation coefficient value across training, validation, testing, and overall comparison shows that the model can accurately forecast the wind mill's current production value. The comparison output variables between the experimental investigations and the ANN-GA projected values are displayed in Table 1 [20], [21].

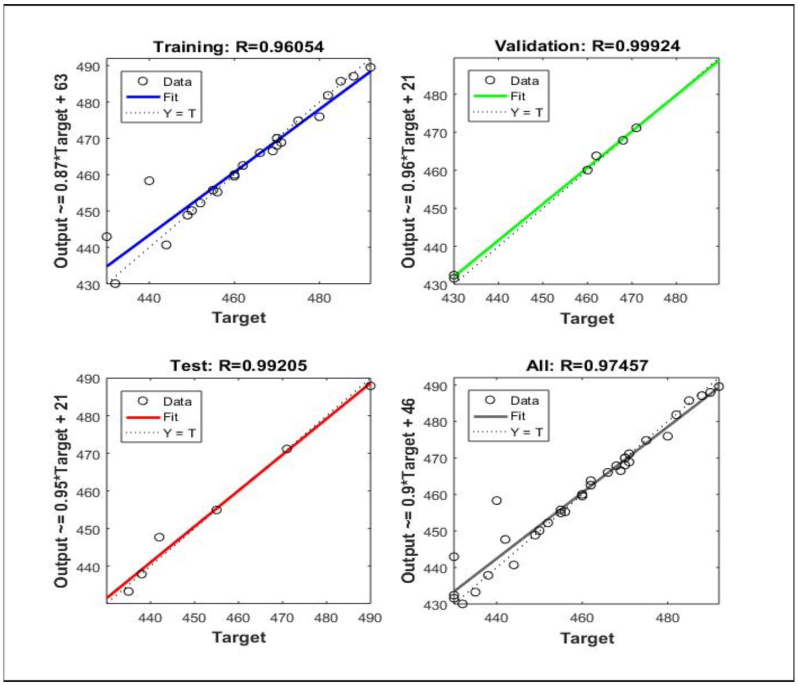

Fig 2. ANN network model output values and the target values of the current output

Table 1. Experimental data and ANN-GA (Genetic Algorithm) Predicted Data

Time	Wind Speed [m/s]	Current [Amp] (Experimental)	Current [Amp] (Predicted from ANN)
30	6.44	460	459.562
60	6.58	470	469.965
90	6.86	490	487.948
120	6.72	480	475.955
150	6.58	470	470.052
180	6.78	485	485.718
30	6.3	450	450.116
60	6.37	455	455.799
90	6.52	466	466.029
120	6.47	462	463.786
150	6.44	460	460.033
180	6.59	471	471.153
30	6.88	492	489.558
60	6.83	488	487.069
90	6.59	471	468.879
120	6.56	469	466.526

150	6.32	452	452.211
180	6.28	449	448.877
30	6.44	460	459.562
60	6.02	430	431.558
90	6.04	432	430.039
120	6.09	435	433.239
150	6.13	438	437.854
180	6.18	442	447.680
30	6.38	456	455.237
60	6.37	455	455.799
90	6.55	468	467.877
120	6.58	470	468.046
150	6.65	475	474.828
180	6.74	482	481.832
30	6.37	455	454.937
60	6.16	440	458.332
90	6.21	444	440.683
120	6.02	430	432.400
150	6.44	460	460.033
180	6.02	430	442.955
30	6.3	450	450.116
60	6.37	455	455.799
90	6.52	466	466.029
120	6.46	462	462.543
150	6.44	460	460.033
180	6.59	471	471.153

Results and Discussion

The simple design of rotor blades enhanced the wind velocity and thereby generate high currents. Artificial Intelligence (AI) methods, including machine learning and neural networks, have been used successfully to improve wind turbine performance and efficiency. The implementation of AI in wind energy systems has shown promising outcomes, as demonstrated by the case study done in this paper. The case study entailed gathering real-time data from a wind turbine and using AI models to forecast wind speed and direction, optimize turbine performance, and boost energy output. It was shown by the results that artificial intelligence (AI) may greatly raise the overall efficiency of wind energy systems, which will raise output and lower operating expenses. Additionally, by offering more precise forecasts and enhanced grid stability, AI can help with the better integration of wind energy into the system. In summary, this study shows how artificial intelligence (AI) has the power to completely transform the wind energy industry, making it more dependable, effective, and sustainable.

Conclusions

A small fabricated windmill was used to measure the current out on a highway during vehicle movement. The experimental data for seven days at an interval of 30 min. The obtained data was used in Artificial Neural Network-Genetic Algorithm and training and testing. The ANN predicted values were found to be in good concurrence with the experimental data.

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