Design and Analysis of Artificial Intelligence based Approach for Control of Wind Turbine: A Review

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Abstract- *Wind energy is one of the major sources of renewable sources. It has non-polluting and economically viable. The wind turbine generator system is producing electricity from varying wind velocity conditions. It is the fastest growing energy technology in the world. Renewable Energy Sources are those energy sources which are not destroyed when their energy is harnessed. Human use of renewable energy requires technologies that harness natural phenomena, such as sunlight, wind, waves, water flow, and biological processes such as anaerobic digestion, biological hydrogen production and geothermal heat. Amongst the above mentioned sources of energy there has been a lot of development in the technology for harnessing energy from the wind. Generally the main difficulties handicap the control of wind power plants are uncertainty and variability that exist in wind power have always posed challenges for power system operators. So the biggest challenges in wind energy engineering are to integrate the very variable power production from wind turbines into the electrical system. In this paper different techniques of control of wind turbines design and their outcomes are discussed.*

Key Words: Renewable , Turbine, Generator, Rotor, Induction.

1. INTRODUCTION

Renewable Energy Sources are those energy sources which are not destroyed when their energy is harnessed. Human use of renewable energy requires technologies that harness natural phenomena, such as sunlight, wind, waves, water flow, and biological processes such as anaerobic digestion, biological hydrogen production and geothermal heat. Amongst the above mentioned sources of energy there has been a lot of development in the technology for harnessing energy from the wind. Wind is the motion of air masses produced by the irregular heating of the earth's surface by sun. These differences consequently create forces that push air masses around for balancing the global temperature or, on a much smaller scale, the temperature between land and sea or between mountains. [3]

Wind energy is not a constant source of energy. It varies continuously and gives energy in sudden bursts. About 50% of the entire energy is given out in just 15% of the operating time. Wind strengths vary and thus cannot guarantee continuous power. It is best used in the context of a system that has significant reserve capacity such as hydro, or reserve load, such as a desalination plant, to mitigate the economic effects of resource variability. [4]

1.1 A wind turbine- A wind turbine is a rotating machine which converts the kinetic energy in wind into mechanical energy. If the mechanical energy is then converted to electricity, the machine is called a wind generator, wind turbine, wind power unit (WPU), wind energy converter (WEC), or aero generator. Wind turbines can be separated into two types based by the axis in which the turbine rotates. Turbines that rotate around a horizontal axis are more common. Vertical-axis turbines are less frequently used. [6]

1.1.1 Horizontal Axis Wind Turbines: Horizontal-axis wind turbines (HAWT) have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator. Since a tower produces turbulence behind it, the turbine is usually pointed upwind of the tower. Turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted up a small amount. Downwind machines have been built, despite the problem of turbulence, because they don't need an additional mechanism for keeping them in line with the wind, and because in high winds the blades can be allowed to bend which reduces their swept area and thus their wind resistance. Since cyclic (that is repetitive) turbulence may lead to fatigue failures most HAWTs are upwind machines. [7]

Figure1.1: Horizontal axis wind turbines

1.1.2 Vertical axis Wind Turbines: Vertical-axis wind turbines (or VAWTs) have the main rotor shaft arranged vertically. Key advantages of this arrangement are that the turbine does not need to be pointed into the wind to be effective. This is an advantage on sites where the wind direction is highly variable. VAWTs can utilize winds from varying directions. With a vertical axis, the generator and gearbox can be placed near the ground, so the tower doesn't need to support it, and it is more accessible for maintenance. Drawbacks are that some designs produce pulsating torque. Drag may be created when the blade rotates into the wind. [9]

Figure1.2: Vertical axis wind turbine

1.2 Wind Turbine Glossary

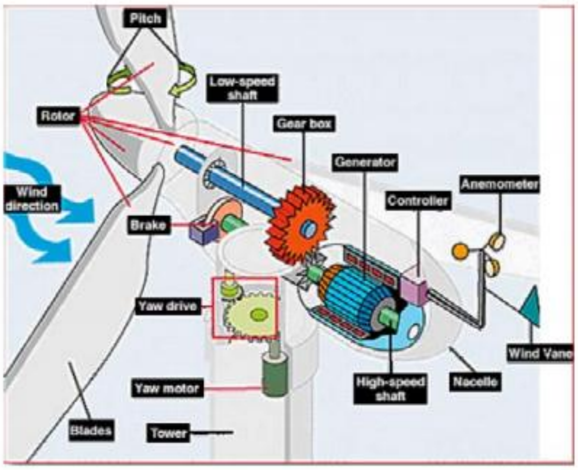


Figure1.3: Parts of wind turbines

Anemometer: Measures the wind speed and transmits wind speed data to the controller.

Blades: Most turbines have either two or three blades. Wind blowing over the blades causes the blades to "lift" and rotate.

Brake: A disc brake which can be applied mechanically, electrically, or hydraulically to stop the rotor in emergencies.

Controller: The controller starts up the machine at wind speeds of about 8 to 16 miles per hour (mph) and shuts off the machine at about 65 mph. Turbines cannot operate at wind speeds above about 65 mph because their generators could overheat.

Gear box: Gears connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1200 to 1500 rpm, the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.

Generator: Usually an off-the-shelf induction generator that produces 60-cycle AC electricity.

High-speed shaft: Drives the generator. Low-speed shaft: The rotor turns the low-speed shaft at about 30 to 60 rotations per minute

Nacelle: The rotor attaches to the nacelle, which sits atop the tower and includes the gear box, low- and high-speed shafts, generator, controller, and brake. A cover protects the components inside the nacelle. Some nacelles are large enough for a technician to stand inside while working.

Pitch: Blades are turned, or pitched, out of the wind to keep the rotor from turning in winds that are too high or too low to produce electricity.

Rotor: The blades and the hub together are called the rotor.

Tower: Towers are made from tubular steel (shown here) or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.

Wind direction: This is an "upwind" turbine, so-called because it operates facing into the wind. Other turbines are designed to run "downwind", facing away from the wind.

Wind vane: Measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.

Yaw drive: Upwind turbines face into the wind; the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw drive, the wind blows the rotor downwind.

Yaw motor: Powers the yaw drive.

1.3 Present Scenario of Wind Power in the World

Today wind power is the most competitively priced technology in many if not most markets worldwide. The emergence of wind/solar hybrids, more sophisticated grid management and increasingly affordable storage begin to paint a picture of what a fully commercial fossil-free power sector will look like. The Global Wind Energy Council (GWEC) released its *Global Wind Report: Annual Market Update* today, showing a maturing industry successfully competing in the marketplace, even against heavily subsidized traditional power generation technologies. More than 52GW of clean, emissions-free wind power was added in 2017, bringing total installations to 539 GW globally. With new records set in Europe, India and in the offshore sector, annual markets will resume rapid growth after 2018.

"Wind power is leading the charge in the transition away from fossil fuels; and continues to blow away the competition on price, performance and reliability", said Steve Sawyer, GWEC Secretary General. "Both onshore and offshore, wind power is key to defining a sustainable energy future". Dramatic price reductions for both onshore and offshore wind continue to surprise. Markets in Morocco, India, Mexico and Canada range in the area of US$ 0.03/kWh, with a recent Mexican tender coming in with prices well below US$ 0.02/kWh. Meanwhile offshore wind had its first 'subsidy-free' bids in tenders In Germany and the Netherlands, with tenders for nearly 2 GW of new offshore wind capacity receiving no more than the wholesale price of electricity. GWEC's rolling 5-year forecast puts the 2018 market at a similar level as 2017, as the dominant EU markets in Germany and the UK will face reductions due to changing regulatory environments, and India's market will drop temporarily due to a 'policy gap' between the old and new systems; but the sector will return to dramatic growth in 2019, will pass the 60 GW milestone in 2020, and move upwards from there to reach a total of 840 GW by 2022.

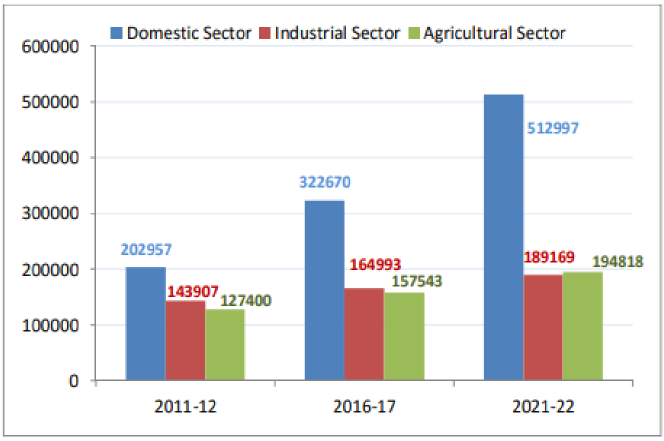
The US market is projected to remain strong at least through 2020, and probably beyond, and Brazil will continue to dominate Latin American markets, although with a new challenger from Argentina. New markets continue to emerge in Africa and Asia, although China will continue to be the dominant market globally, but with less spectacular growth than in the past decade.

Wind penetration levels continue to increase rapidly. Denmark got 44% of its electricity from wind in 2017, and Uruguay more than 30%. In 2017, wind supplied 11.6% of the EU's power, led by Denmark, Portugal and Ireland at 24% and Spain and Germany just under 20%. Four US states get more than 30% of their electricity from wind, as does the state of South Australia, and a number of states in Germany. "Driven by the improving economics of wind power, as well as solar and storage, the outlines of a 100% renewable energy system is becoming clear", concluded Sawyer.

1.4 Future Trends in Power Sector

In estimation with per capita GDP growth at 7.5% and electricity price grows at the rate of 2% per year the electricity consumption in 2011-12, 2016-17 and 2021-22 would be 457639 GWh, 514802 GWh and 595134 GWh respectively. A capacity addition of 78,700 MW is planned for 11th plan i.e. till 2011-12. This is however not anticipated to be achieved (likely achievement will be around 50 %) and the 12th Plan will commence with a deficit addition. The long term forecast of electrical energy consumption at the end of 11th Plan, 12th Plan and 13th Plan may be 7582.547 GWh, 7133809 GWh and 3093266 GWh respectively.

The predicted electricity consumption (in GWh) of different sector is shown in the figure below.



In the above figure the consumption in domestic sector is estimated with conditions of GDP growth at 8% and while agriculture sector is estimated to grow at 4% and industrial sector which has recovered from the recession with a positive growth rate is estimated with a growth rate of 10%. In all these cases, the electricity price is rising at 2% per year. The peak electricity load in the country estimated to rise up to 298253 MW in 2021-22. In the near future, in 2011-12 the peak load may go up to 302806 MW from the current level of 14672 MW.

2. RELATED WORK

Amina Bouzekri et all in [1] presented a new artificial intelligence-based detection method of open switch faults in power converters connecting doubly-fed induction (DFIG) generator wind turbine systems to the grid. The detection method combines a simple Fault Tolerant Control (FTC) strategy with fuzzy logic and uses rotor current average values to detect the faulty switch in a very short period of time. In addition, following a power switch failure, the FTC strategy activates the redundant leg and restores the operation of the converter. In order to improve the performance of the closed-loop system during transients and faulty conditions, current control is based on a PI (proportional-integral) controller optimized using genetic algorithms. The simulation model was developed in Matlab/Simulink environment and the simulation results demonstrate the effectiveness of the proposed FTC method and closed-loop current control scheme.

Arama Fatima Zohra et al in [2] presented the dynamic response of the wind energy conversion system (WECS) based on the Doubly Fed Induction Generator (DFIG). The DFIG rotor is connected to the grid via a converter. The active and reactive power control is realized by the DFIG rotor variables control, using the field oriented control (FOC). The vector control of DFIG is applied by the use of tow regulators PI and the neural network regulator (NN). The generator mathematical model is implemented in Matlab/ Simulink software to simulate a DFIG of 1.5 MW in order to show the efficiency of the performances and robustness of the studied control systems. The simulation obtained results shows that the robustness and response time of the neural network regulator is better than those obtained by the PI classical regulator.

Adrian Stetco et al in [3] discussed literature on machine learning (ML) models that have been used for condition monitoring in wind turbines (e.g. blade fault detection or generator temperature monitoring). We classify these models by typical ML steps, including data sources, feature selection and extraction, model selection (classification, regression), validation and decision-making. Our findings show that most models use SCADA or simulated data, with almost two-thirds of methods using classification and the rest relying on regression. Neural networks, support vector machines and decision trees are most commonly used. The reviewed studied focus on various tasks, including blade fault detection, generator temperature monitoring, power curve monitoring, etc.

Tayeb Brahimi et al in [4] Predicted wind speed for wind energy conversion systems (WECS) is an essential monitor, control, plan, and dispatch generated power and meets customer needs. The Kingdom of Saudi Arabia recently set ambitious targets in its national transformation program and Vision 2030 to move away from oil dependence and redirect oil and gas exploration efforts to other higher-value uses, chiefly meeting 10% of its energy demand through renewable energy sources. In this paper, we propose the use of the artificial neural networks (ANNs) method as a means of predicting daily wind speed in a number of locations in the Kingdom of Saudi Arabia based on multiple local meteorological measurement data provided by K.A.CARE. The suggested model is a feed-forward neural network model with the administered learning technique using a back-propagation algorithm. Results indicate that the best structure is obtained with thirty neurons in the hidden layers matching a minimum root mean square error (RMSE) and the highest correlation coefficient (R). A comparison between predicted and actual data from meteorological stations showed good agreement. A comparison between five machine learning algorithms, namely ANN, support vector machines (SVM), random tree, random forest, and RepTree revealed that random tree has low correlation and relatively high root mean square error.

Hadjira Bouazza et al in [5] suggested that Power converters play a key-role in the grid-integration of wind power generation and as any physical device, they are prone to mal function and failure. There is, therefore, a need for converter health monitoring and fault detection to ensure a reliable and sustainable operation of the wind turbine. This paper presents different artificial intelligence-based fault detection using fuzzy and neuro-fuzzy techniques. The proposed methods are designed for the detection of one or two open-circuit fault in the power switches of the rotor side converter (RSC) of a doubly-fed induction generator (DFIG) wind energy conversion system (WECS). In the proposed detection method only the average values of the three-phase rotor current are used to identify the faulty switch. Alongside these condition monitoring strategies, the paper also present two fuzzy logic-based controllers for the regulation of the real and reactive power flow between the grid and the converter. The performances of the controllers are evaluated under different operating conditions of the power system and the reliability, feasibility and the effectiveness of the proposed fault detection have been verified under various open-switch fault conditions.

Nadia Masood Khan et al in [6] presented Supervisory Control and Data Acquisition (SCADA) systems used in wind turbines for monitoring the health and performance of a wind farm can suffer from data loss due to sensor failure, transmission link breakdown or network congestion. Sensory data is used for important control decisions and such data loss can make the failures harder to detect. This work proposes various solutions to reconstruct the lost information of important SCADA parameters using Linear and non-linear Artificial Intelligence (AI) algorithms. It comprises of three major contributions; signal reconstruction from other available SCADA parameters, comparison of linear and non-linear AI models, and generalization of the AI algorithms between turbines. Experimental results demonstrate the effectiveness of the developed methodologies for reconstruction of the lost information for valuable planning decisions.

Bharat Singh et al in [7] presented a computational strategy directed more towards intelligent behavior is employed as a tool for fast, accurate, and efficient control of PES used in double fed induction generator (DFIG) based wind power generation. The conventional proportional-integral (PI) controller is replaced with a nonlinear adaptive neuro-fuzzy inference system (ANFIS) based controller. The fundamental concepts of CI based techniques like ANN, fuzzy logic, hybrid methods, and evolutionary programming are briefly described. The design and procedure for selection of parameters and training of ANFIS are described. A unified architecture (UA) of the DFIG and its control strategies is also addressed. The performance of the conventional PI and ANFIS based controllers is compared using simulation results on a detailed power system test model having wind farms.

Amina bzkr et al in [8] presented a new artificial intelligence-based detection method of open switch faults in power converters connecting doubly-fed induction (DFIG) generator wind turbine systems to the grid. The detection method combines a simple Fault Tolerant Control (FTC) strategy with fuzzy logic and uses rotor current average values to detect the faulty switch in a very short period of time. In addition, following a power switch failure, the FTC strategy activates the redundant leg and restores the operation of the converter. In order to improve the performance of the closed-loop system during transients and faulty conditions, current control is based on a PI (proportional-integral) controller optimized using genetic algorithms. The simulation model was developed in Matlab/Simulink environment and the simulation results demonstrate the effectiveness of the proposed FTC method and closed-loop current control scheme.

Santhosh M et al in [9] suggested that wind power is playing a pivotal part in global energy growth as it is clean and pollution-free. To maximize profits, economic scheduling, dispatching, and planning the unit commitment, there is a great demand for wind forecasting techniques. This drives the researchers and electric utility planners in the direction of more advanced approaches to forecast over broader time horizons. Key prediction techniques use physical, statistical approaches, artificial intelligence techniques, and hybrid methods. An extensive review of the current forecasting techniques, as well as their performance evaluation, is here presented. The techniques used for improving the prediction accuracy, methods to overcome major forecasting problems, evolving trends, and further advanced applications in future research are explored.

Matteo Mana et al in [10] suggested that Accurate wind power forecast is very important in order to construct smart electric grids. Nevertheless, this task still constitutes a challenge because wind is a very variable and local phenomenon. It is difficult to downscale information coming from Numerical Weather Prediction (NWP) models down to wind farm level and this is especially true onshore, in complex terrain conditions. Artificial Intelligence often comes at hand, for its power in learning what is hidden inside data: Artificial Neural Networks (ANN) are therefore commonly employed for wind power forecast. In this work, a pure ANN method is compared against a hybrid method, based on the combination of ANN and a numerical method based on physically-consistent assumptions (Computational Fluid Dynamics). Both approaches are validated against the SCADA data of a wind farm sited in Italy in a very complex terrain. It arises that the two methods have overall similar performances on average. However, pure ANN turns out to forecast better at mid-energy levels and during cut-off events at the highest wind speed, whereas the hybrid method forecasts better during low and high wind speed ranges. This makes the two approaches complementary and promising for future applications through an ensemble strategy.

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