A Review on Wind Power Generation using Neural and Fuzzy Logic

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Abstract: *Alternative energy sources have become a necessity for the socio-economic growth of a country; fossil fuels are declining and by increasing the power demand, the world is on the edge of a global energy crisis. Furthermore, due to the widespread use of traditional energy sources, this creates pollution and global warming effects on the environment. In the light of this, renewable energy such as the wind and solar energy are highly significant and viable solution in order to fulfil power demand, due to its low operating costs and available in bulk quantities which make it exploitation beneficial for the development of any country. Besides that, for over the past decades, the researchers have been working on this enormous challenge. In this review article, we put forward a wide-ranging and significant research conducted on the state-of-the-art control methodologies for wind energy systems. Therefore, author's main aim is to ensure up-to-date knowledge of wind energy control techniques for the research community and can be considered for future directions. In the available literature, we have summarized numerous wind turbine control techniques with their performance. Furthermore, prospective future advancements and gaps have also been examined comprehensively, and omissions of other researchers are purely unintentional.*

Key words: *Wind, Power generation, Neural network, Fuzzy logic, Review*

1. Introduction:

In the area of wind power generation systems, where the wind speed varies considerably, VSG (variable speed generation) is more interesting than fixed speed systems. In these systems, a MPPT (maximum power point tracking) adjusts a system quantity to maximize turbine power output. The generator that operates at variable speeds is extremely attractive. So to exploit these advantages in wind power generation area, new control strategies should be designed, by taking into account all the parts of the system such as the grid, the structure complexity of the DFIG (doubly fed induction generator) with respect to the quality of the energy to be generated. In the absence of suitable control of the produced active and reactive powers many problems may appear when the generator is connected to the grid, such as, low power factor and harmonic pollution. Several designs and arrangements have been investigated by using predictive functional and internal mode controllers, where satisfactory results in power response compared with those of the traditional methods, using a conventional PI (Proportional Integral) controller. However, these new methods are hard to implement, due to their complicated structures. Among control objectives of WECSs (wind energy conversion system) much work has been achieved in the control of variable speed TSR (Time Speed Ratio) and/pitch controlled wind turbines with the main goal to bring them to the optimum operating point for maximum power conversion. Many control schemes has been proposed for this purpose [9e13]. Adaptive control, which is a promising approach since it provides controllers the ability of learning and auto-adjustment as systems and/or environment change. This feature is particularly useful for DFIGs which are immersed in highly stochastic and varying winds. Different adaptive control schemes were proposed for achieving maximum power capture in WECSs , the authors proposed an adaptive fuzzy control of a PMSG based wind turbine, which dealt successfully with the uncertainties in the turbine parameters, in Ref. an adaptive control scheme using radial basis function was proposed, in both works, a sliding supervisory term is introduced, this last can be a source of chattering and complexity, another limitation of this approach is the boundedness assumptions made on the control gain, its derivative and on the structural error, and the dynamics field vector.

_Literature Survey:

Y. Erramia (2013) et al. presented the study of a Wind Energy Conversion System (WECS) based on Permanent Magnet Synchronous Generator and interconnected to the electric network is described. The effectiveness of the WECS can be greatly improved, under Grid Fault, by using an appropriate control. So, the control strategy combines Maximum Power Point Tracking (MPPT) and a pitch control scheme to maximize the generated power. Consequently, WECS can not only capture the maximum wind energy, however it can also maintain the frequency and amplitude of the output voltage. Simulation results have shown the effectiveness of the proposed control strategy for WECS based on the PMSG.

Bipin Biharee Srivastava (2014) et al. proposed wind energy has gained a growing worldwide interest due to the nonstop rise in fuel cost. The main aim of the wind-energy system is to extract the maximum power present in the wind stream. In order to extract the highest power, the maximum power point tracking (MPPT) algorithm is used. This paper proposes the fuzzy logic MPPT controller to track the maximum power from the wind generation system. The maximum power is achieved based on the rotor speed of the wind system which consists of wind turbine and PMSG. The error and change in error is given as input to the fuzzy logic and its output is connected to the boost converter. The voltage from the dc link is controlled by the Voltage Source Inverter (VSI), and it is placed in grid side converter control. The proposed system is designed and evaluated in MATLAB/SIMULINK. Simulation results show the good dynamic performance of the proposed system.

Naziha Harrabi (2015) et al. presented a topology of control dedicated to a wind energy conversion system (WECS) using a Permanent Magnet Synchronous Generator (PMSG) and AC/DC rectifier in the objective of ensuring maximum power generation. The control aim is to track the generator reference speed according to the wind velocity variation in order to maximize the power output and enhance system performance. For this purpose, the WECS modelling is carried out on the basis of Takagi–Sugeno (T-S) fuzzy model. The control gains are calculated by solving Linear Matrix Inequalities (LMIs). Finally, simulation results have been presented to check the proposed approach efficiency.

Ramji Tiwari (2016) et al. proposed a comparative analysis of different control methods to extract the maximum power from Permanent Magnet Synchronous Generator (PMSG) based Wind Energy Conversion System (WECS) under different wind speed condition is presented. The WECS consists of a wind turbine, a PMSG and a DC/DC converter which is connected to a DC load. The Maximum Power Point Tracking (MPPT) control technique compared here are Proportional Integral (PI) control, Perturb and Observe (P&O) method and Fuzzy Logic Controller (FLC). The parameters considered for analysing the efficiency of the MPPT controller is the output DC voltage and power across the load. The steady state voltage and the dynamic response of the system under different wind speed is considered to justify the overall efficiency of the controllers. The system is designed and configured in MATLAB/SIMULINK software and the results are validated.

S. Marmouh (2016) presented this paper is to control a Wind Energy Conversion System (WECS), equipped with a Permanent Magnet Synchronous Generator (PMSG), for maximum power generation. Maximum Power Point Tracking (MPPT) control algorithm is applied to a PMSG whose stator is connected to the grid through a back-to-back AC-DC-AC converter. The Stator Side Converter (SSC) is controlled in such a way to extract the maximum power, for a wide range of wind speed. The Grid Side Converter (GSC) is controlled in order to ensure a smooth DC link voltage between the two converters. The presented simulation results demonstrate the performance and the effectiveness of the control strategy.

Sabri Boulouma (2016) et al. proposed a radial basis function (RBF) neural networks sliding mode controller is designed for a permanent magnet synchronous generator (PMSG) based wind energy conversion system (WECS). The aim is to ensure maximum power capture. Within this control scheme, the WECS nonlinear control affine model is transformed into the canonical form via a diffeomorphism transformation. Afterwards, a RBF neural networks based controller is built around the approximation of an ideal sliding mode controller to ensure reference tracking. In this controller the system parameters are approximated through an RBF neural network, and then these approximations are substituted into their counterparts from the ideal controller. The parameter update laws are derived based on Lyapunov synthesis. A compensation term is appended to the composite controller to ensure robustness against approximation errors. Stability and tracking properties are proved using Lyapunov analysis. A numerical simulation is carried out on a typical 3kW PMSG based wind turbine to access the effectiveness of the proposed controller. The results are then discussed to assess the effectiveness ofthe proposed neural networks controller.

U. Sri Anjaneyulu (2016) et al. presented Renewable Energy Sources (RES) are nowadays growing rapidly at the distribution level and it employs power electronic converters to ensure reliable operation to the customers. Among the RES, wind energy is now firmly established technology for electricity generation. This paper proposes a conventional PI controller and Artificial Neural Network (ANN) controller to GSC of PMSG, which can obtain zero error in current controller. The grid side converter plays a dual role of interfacing the wind energy to grid as well as to supply reactive power as demanded by the non-linear load connected at the PCC. In this, the system is verified under two considerations: i.e. grid connected PMSG based wind system under fault analysis and comparison study of Proportional integral (PI) controller and ANN Controller to the PMSG grid-side converter Presents of Non-Linear load. Furthermore, the proposed system implemented in Matlab/Simulink and the effectiveness of the proposed Grid based PMSG wind system under grid fault conditions are studied.

Chakib Chatri (2018) et al. proposed a new fuzzy control strategy of a variable speed wind based on Permanent Magnet Synchronous Generator (PMSG) .The construction of a Takagi-Sugeno (T-S) fuzzy controller is built to drive the states of the PMSG to track their optimal trajectory. Meanwhile, the Parallel Distributed Compensation (PDC) strategy is used to maximize the power output and enhance the system performance. In addition, the gains of the proposed controller are calculated using Linear Matrix Inequality (LMI) method. According to simulation results, at a wide range of wind, the proposed control strategy is significantly more efficient than Proportional Integral (PI).

Lavudya Anand (2019) et al. proposed application of Adaptive Neuro Fuzzy Inference System (ANFIS) for Proportional Integral Controller based control scheme to enrich the performance of a Wind Energy Conversion System (WECS). The wind turbine drives a Permanent Magnet Synchronous Generator (PMSG), which is connected to the power grid through a frequency converter, Power Electronic Converters and Filter. A cascaded ANFIS-PI controller is introduced in Pitch Control Method to control the speed of wind turbine. ANFIS is a non-linear, adaptive, and ruggedness controller, which integrates the advantages of the Artificial Neural Network (ANN) and fuzzy. The Conventional PI controller based coordinated control scheme is easy and provides a good performance. But, with varying parameters of the grid, especially at the time of grid disturbance due to LLL Fault; the conventional PI controller cannot effectively control the system. To perform this online returning of parameters, ANFIS controller based coordinated control scheme is proposed here. MATLAB simulations are executed to check the effectiveness of the proposed ANFIS controller based coordinated control scheme on a typical arrangement of MW-size Wind Farm connected to a Grid. It has been noticed that at the time of grid disturbance, the reactive power requirement of the PMSG based WECS and rotor speed of the PMSG based WECS is efficiently controlled by the ANFIS based controller. The simulations have presented how advantageous an ANFIS based controller is over a conventional PI controller.

Youjie Ma (2019) et al. presented wind energy conversion systems (WECSs) have attracted attention due to their effective application in renewable energy sources. It is a complex system with multi-variables, strong coupling, non-linearity, and variable parameters; however, traditional control systems are inadequate in answering the demands of complex systems. In order to solve the complexity and improve the transient stability during grid faults and power fluctuations, this paper proposes a fuzzy logic system with the linear extended state observer (FLS-LESO) applied to WECSs based on a permanent magnet synchronous generator (PMSG). The FLS-LESO consists of a fuzzy logic controller, a conventional PD controller, and the linear extended state observer (LESO). This paper analyzes the mathematical model of a wind power system and combines it with LESO to improve the estimation accuracy of the observer and further improve the control performance. In the simulation study, the control performance of the FLS-LESO was also tested under various operating conditions using the MATLAB/Simulink simulation platform to verify the correctness and effectiveness of the control system.

Table 2.1: Comparison between findings

Reference No.	Author	Algorithm Used	Findings
[1]	Bipin Biharee Srivastava et al.	Fuzzy control	Quick response, limit insensitivity, high efficiency and reliability
[2]	Chakib Chatri et al.	T-S fuzzy control	Optimum power obtained
[3]	Lavudya Anand	Neuro Fuzzy control	Efficient, smaller settling time
[4]	Naziha Harrabi et al.	T-S fuzzy control, linear matrix inequality (LMI)	Optimum power, Quick response
[5]	Ramji Tiwari et al.	Fuzzy Logic Controller	Stable, faster tracking, efficient
[6]	S. Marmouh et al.	DC Link Control; Fuzzy Logic Controlle	Mppt for a wide range of wind speed, smooth DC voltage
[7]	Sabri Boulouma et al.	Sliding Mode Control RBF Neural Networks	Robust,good speed tracking and power coefficient regulation
[8]	U. Sri Anjaneyulu et al.	PI, ANN	Less harmonic distortion, neuro controller shows the better results as compared to conventional PI controller
[9]	Y. Errami et al.	Vector Control; Variable-speed control	Regulate both the reactive and active power independently
[10]	Youjie M et al.	fuzzy logic system, linear extended state	Transient stability during grid faults and wind turbine power fluctuation

2. Proposed Work:

This paper is an alternative approach which has been proposed using optimized Neural Networks and Fuzzy Logic controllers to control the active and reactive powers through the rotor circuit, these types of controllers have been used due to their characteristics and benefits, such as their robustness, easy to understand and design, via the introduction of human expertise. The main objective of this work is to propose new neural network and adaptive fuzzy controller schemes for maximum wind power capture, applied to the doubly fed generator.

Wind Energy Conversion System:

A WECS consists of a blade generator, control system, transformer, and power electronics components, as shown in Figure 3.1. Wind turbines convert wind energy into electrical energy. The direct-drive permanent magnet synchronous wind turbine is connected to the power grid through full power back-to-back converters. The machine-side converter controls the motor speed or torque to realize the maximum power tracking of wind energy. The grid-side converter mainly stabilizes the DC bus voltage and controls the grid-connected power factor and power quality.

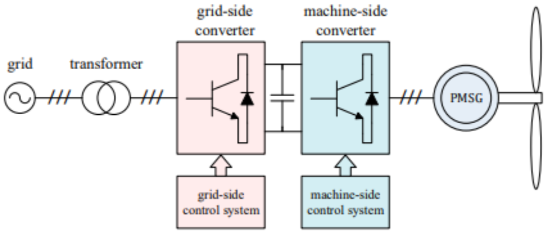

Figure 3.1: Schematic diagram of the direct-drive permanent-magnet wind generator

The topological structure of WECS is shown in Figure 3.2. The inverter circuit adopts full bridge AC/DC converter. Bidirectional switching devices use six common emitter insulated-gate bipolar transistor (IGBT) switch sequences. Rg, Lg and Cg respectively represent the internal resistance, filter inductance and capacitance of the grid-side filter. The idc is DC current and udc is DC voltage. he dc i is DC current and dc u is DC voltage and meet the power quality requirements of smart grid, it is necessary to control the grid-connected inverter of wind power.

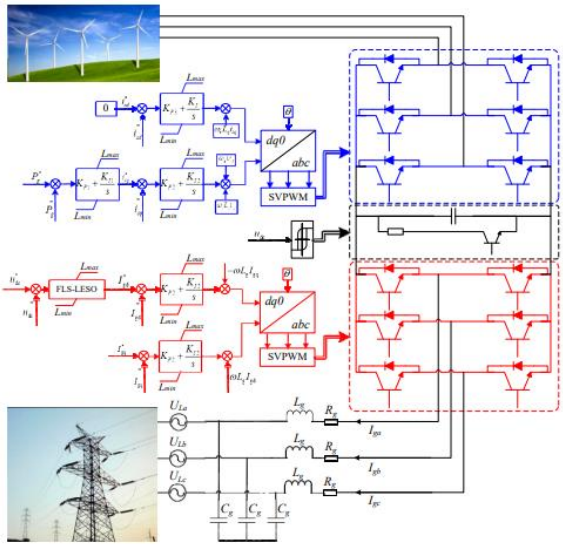

Figure 3.2: Topology and control structure of wind energy conversion system

According to the topology shown in Figure 3.2, KVL three-phase voltage equation can be obtained

$$\begin{bmatrix}Uga\\Ugb\\Ugc\end{bmatrix} = \begin{bmatrix}ULa\\ULb\\ULc\end{bmatrix} + Rg \begin{bmatrix}Iga\\Igb\\Igc\end{bmatrix} + Lg\ d/dt \begin{bmatrix}Iga\\Igb\\Igc\end{bmatrix} \ldots(1)$$

where Uga, Ugb and Ugc are the inverter voltages of three-phase network side. ULa, ULb and ULc represent three-phase grid voltages. Iga, Igb and Igc depict three-phase grid-side inverter currents. After conversion:

$$\begin{bmatrix}Ugd\\Ugq\end{bmatrix} = \begin{bmatrix}ULd\\ULq\end{bmatrix} + Rg \begin{bmatrix}Igd\\Igq\end{bmatrix} + Lg\ d/dt \begin{bmatrix}Igd\\Igq\end{bmatrix} + Lg \begin{bmatrix}-wIgq\\wIgd\end{bmatrix} \ldots\ldots(2)$$

where Ugd and Ugq are the voltages of the q and d loops in the inverter on the grid-side, respectively. The ULd and ULq depict the voltages of the d and q loops in the three-phase grid voltage, respectively. Igd and Igq represent d and q loops currents of the grid-side inverter, and ω is the electric angular of the grid. The Equation (4) shows that Igd and Igq are controlled by Ugd and Ugq, and are influenced by ωLgIgq and ωLgIgd, voltage drop RgIgd and RgIgq, and grid voltage ULd and ULq.

Neural network and fuzzy logic controllers:

The idea is to substitute the fuzzy controller (rotor side and grid side) by neural network regulator, for this, a graphic interface based on NNFTool (Neural Network Fitting Tool) in Matlab software tool is used for the learning, this step is a back propagation of the error of the output layer to the input layer. It can be done by modifying and adapting the weights of NN (Neural Network) to converge to the optimum values and constants (the learning coefficient must be 0.93 or greater). The problem is to find a structure (number of hidden layers and number of neurons in each hidden layer), which gives better results. For this, purpose several tests to determine the optimal network architecture have been carried. The most efficient choice was to take a neural network structure in an input layer to a neuron, a single hidden layer with three neurons and an output layer neuron.

With the complexity of the control system and the controlled object, it is manifested by strong coupling, time-varying parameters and nonlinear characteristic of the control system. The more prominent problem is that the information quantity obtained from the system object is relatively reduced, while the requirement for control performance is increasingly higher. Many times, it is difficult or impossible to establish an accurate mathematical model of the controlled object. The experience of manual control is described in language and a series of conditional statements are formed, that is, control rules. Using fuzzy theory, fuzzy language variables and fuzzy logic reasoning, the fuzzy control rules are upgraded to numerical operations, and the computer USES programs to realize these control rules. In this way, computer simulation can be used to automatically control the controlled object.

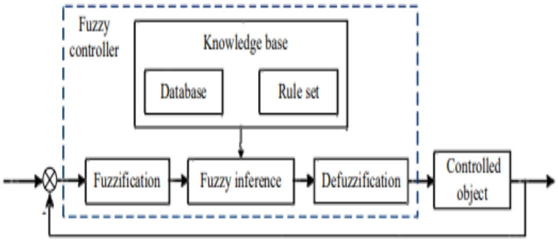

Figure 3.3: Fuzzy control structure

Conclusion:

Generally, global power demand is increasing day-by-day due to the rapid population growth. Renewable resources such as wind energy must be enhanced in order to fulfill the energy demand because it's clean and free of cost source with high global potential. This short survey brings the attention to the scientists, researchers and experts in the cost function optimization and control techniques of wind energy conversion systems. At present, it confirms that most of developed and developing regions are working to devise efficient and reliable control techniques for wind energy conversion systems. There has grown up to be an increasing trend towards wind turbine control systems and optimization approaches. Furthermore, various intelligent control systems have been added with frequent algorithms in order to maximize the efficiency of wind energy conversion systems due to unreliable wind conditions. This brief review of the state of art focuses on the control of wind energy conversion system techniques such as proportional integral derivatives (PID), predictive, adaptive, robust, optimal, sliding mode, neural network, and fuzzy logic. The review, in terms of all control strategies, indicated that the sliding mode controller design technique is more reliable, useful, accurate, and has the speedy action against wind turbine system disturbances. Furthermore, in recent times soft controller techniques such as: neural network, fuzzy logic, and genetic algorithms have significantly grown owing to their most attractive characteristics of nonlinear classification and control. Finally, it was investigated that above discussed controller concepts for wind energy conversion systems make it possible to exploit the greatest features of both hard and soft control methods. Several parts acknowledged for the future prospects of wind energy conversion system are described as follows:

- More appropriate and precise physics base selfmotivated, dynamic form of both constraints such as: lumped and distributed to existing future wind energy conversion systems.

- Most important future development of the research study must consist a prerequisite of the effective control strategy approaches for the evaluation of wind energy conversion systems.
- More significantly, various control systems should be developed for predicting the energy demands.
- More advanced controller techniques for robust, adaptive, optimal, analytical model, complex model, and with industry standard embedded flexible control system for the integration of wind turbine systems.
- Various up-to-date controller algorithms are known as software based techniques such as fuzzy logic, genetic logic algorithm, computer programming, artificial neural network (ANN), and hybrid techniques, etc. probabilistic interpretation and much more need to be future research objectives.
- More advanced software tools for sculpting, drawing, development, analysis, testing and justification of the abilities and modularity of a wind energy conversion system integrated with AC-grid and the internet.

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