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Review Article

An Extensive Review on Fuzzy Logic Control of DFIG-based Wind Turbine

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ABSTRACT

It is quite accepted that the earth's fossil energy resources are limited, and the cost of global oil, coal and gas production continues to rise beyond their peak. Fossil fuels belong to finite sources and so will be completely exhausted one day or the other. Comparing to the above case renewable energies have been in a great demand due to absence of the emissions of poisonous gases like carbon dioxide and sulphur dioxide. The various types of renewable energy sources contributing to current energy demand consist of water, wind, solar energy and biomass. However, the major drawback suffered by hydroelectric power plants is its expensive and costly nature to build and also the plants must operate for a long time to become profitable. The creation of dams may even lead to flooding of lands leading to environmental destruction. Similarly solar energy can only be extracted from solar thermal collectors in the presence of sunlight.

KEYWORDS

Doubly fed induction generator (DFIG), Power control, fuzzy logic, PI controller.

1. INTRODUCTION

Renewable energy resources have gained significant attention of the industry and the academic researcher, because it is environmentally friendly. Wind turbines usually operate under variable speed operation to provide efficient energy, with the power extracted contributing a significant proportion of consumers' electrical power demands. In fact, 20% of the entire electricity consumption in Denmark is now provided by wind energy. In recent years, several different power converter techniques have been developed to integrate wind turbines with the electrical grid. The use of electronic power converters allows for variable speed operation of wind turbines as well as enhanced power extraction. In variable speed operation, a control method is required that extracts maximum power from the turbine while providing constant grid voltage and frequency. A wide range of control schemes, varying in cost and complexity, have been investigated for previously considered conversion systems.

All of the control schemes integrated with power electronic converters are designed to maximize power output at every possible wind speed. These speeds can range from cut-in to rated, and are specific to the size and type of generator being used in the Wind Energy Conversion System (WECS). A WECS based on Doubly Fed Induction Generator DFIG has several advantages. For instance, it decreases stress on the mechanical structure, reduces acoustic noise, and offers the possibility of regulating both active and reactive power by using classical d-q control method. Another advantage of a DFIG system is that the back-to-back Pulse Width Modulation PWM converters connected between the grid and the induction machine rotor circuit are sized for only a portion (approx. 30%) of the generator's full power. Wind turbine generators (WTGs) can achieve maximum wind power provided at various wind speeds by correctly adjusting the shaft speed.

Wind turbines can either operate at fixed speed or variable speed. For a fixed-speed wind turbine the generator is directly connected to the electrical grid. For a variable- speed wind turbine the generator is controlled by power electronic equipment. There are several reasons for using variable-speed operation of wind turbines; among those are possibilities to reduce stresses of the mechanical structure, acoustic noise reduction and the possibility to control active and reactive power. Most of the major wind turbine manufactures are developing new larger wind turbines in the 3-to-6-MW range. These large wind turbines are all based on variable-speed operation with pitch control using a direct-driven synchronous generator (without gear box) or a doubly-fed induction generator. Fixed-speed induction generators with stall control are regarded as unfeasible for these large wind turbines. Today, variable-slip, i.e., the slip of the induction machine is controlled with external rotor resistances, or doubly-fed induction generators are most commonly used by the wind turbine industry for larger wind turbines.

A wind turbine extracts the maximum amount of energy from the wind when operating at an optimal rotor speed, which again depends on speed of wind. The optimal rotor

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speed varies due to the variable nature of the wind speed. Research shows that variable speed operation of the rotor Shows in a higher energy production compared to a system operating at constant speed. A wind turbine model consists of blades, a generator, a power electronic converter, and power grid. Blades are used to extract power from the wind. By operating the blades at optimal tip speed ratio, maximum amount of energy can be extracted from the variable speed wind turbine. The maximum power point tracking (MPPT) control of variable speed operation is used to achieve high efficiency in wind power systems. The MPPT control is operated using the machine side control system. The function of pitch angle control scheme is to regulate the pitch angle by keeping the output power at rated value even when the wind speed experiences gusts. The double fed induction generator is associated with AC-to-AC converter, where generator is directly grid connected through the stator windings, keeping into account the grid voltage and frequency fixed. While the rotor windings are fed by rotor side converter at variable frequency through slip rings.

Characteristics curve stating the relation of power, torque to rotor speed was coded for different wind velocities. Plotting was done in order to extract maximum amount of energy that could be converted to useful mechanical power. Implementing grid side using only PI controllers are shown that in variation of the dc link voltage. Therefore, a fuzzy PI controller was used instead of PI controllers to improve the dynamic response of the system.

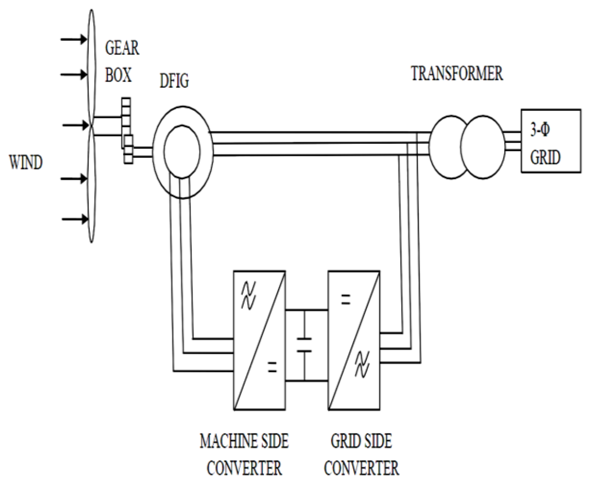

Fig.1.1 DFIG based Wind Energy Conversion System.

2. DOUBLY FED INDUCTION GENERATOR

Doubly fed induction generator is a wound rotor induction generator, where the stator windings are directly linked to the grid while in the rotor side the windings are associated through slip rings to a three phase converter. Wound rotor is used in DFIG so that current could be fed from the rotor side as well as stator side. Operation of the DFIG can be done in standalone and also in grid connected mode. Rotor windings of an induction generator are connected to a power electronic converter, which can vary the voltage applied to the rotor windings. The major advantage of this scheme is a variable rotor speed is achieved, when connected to a constant grid frequency. Unbalanced grid connections, reduces the efficiency of the DFIG as the grid voltage is affected.

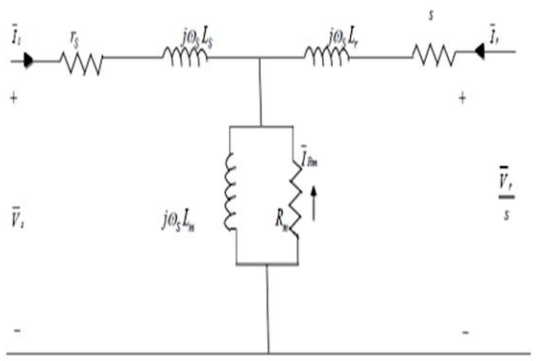

Fig. 2.1 Circuit Diagram of DFIG.

This problem is tackled by DFIG as it can absorb as well as produce efficient quantity of reactive power from or to the grid so as to sustain the proper regulation of the voltage. Synchronous generators, is not directly related to the grid but connected through a medium of converter. In case of a grid connected system, the objective is to generate output voltage of constant frequency from a variable speed operation of the shaft. Although the rotational speed varies, the DFIG could still supply power at constant frequency as well as voltage. DFIG behaves superior to Synchronous generator as it allows the maximum power point tracking, higher efficiency of the turbine, capable to control at unity power factor and finally the improved amount of power quality achieved. Due to these reasons DFIG is gaining popularity for its variable speed among other generators of the wind energy conversion systems.

Design of Fuzzy Controller

The PI controllers always have a very vital role concerning the constancy of the power system. However, the performance of the double fed induction generator greatly depends on the suitable choice of the control gain parameters of the PI. The difficulty regarding the PI controller gain is the fine tuning of the controller so as to achieve the optimal operation of the task. The major drawback of the PI controller is faced when the process is nonlinear and also when the system is having oscillations. Considering all these facts, a fuzzy logic controller was implemented. The advantage regarding fuzzy controller is the systematic approach to control a non-linear based procedure depending on the knowledge and experience based of human being. A fuzzy controller can use multiple inputs and multiple output variables. The operation of fuzzy controller:

Fuzzification

The term fuzzification means to fuzzify the data. This is done by converting the classical set to fuzzy set. For this process we need different fuzzifiers such as Triangular, Trapezoidal, Singleton and Gaussian. With the help of these fuzzifiers we assign some membership function to each and every input and convert it into fuzzy set.

Deffuzification

It is a process of converting a fuzzy set into classical set. It is the inverse process of fuzzification. It is of much importance as by defuzzification process we convert the fuzzy values back into the classical or crisp values. There are different methods for defuzzification such as the centroid method, bisector method, largest of maximum, middle of maximum and finally the smallest of maximum. Among all of this the most efficiently used defuzzification method is the centroid method. A fuzzy controller can operate in a broad range of operations along with the variation of the parameters and load existence as compared to PI controllers. Depending on the control requirements and operational conditions of the DFIG, a fuzzy PI control strategy is designed. Input to the fuzzy PI controller is the error, which is continuously tracked and automatically corrected by the dynamic performance.

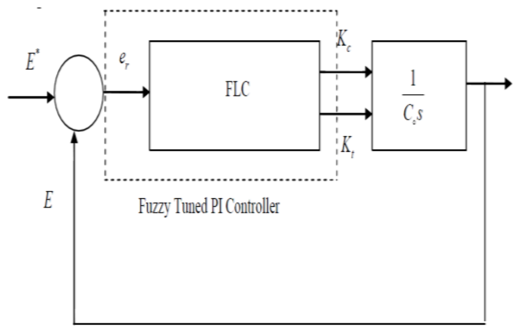

Fig. 2.2 Block Diagram of Fuzzy Tuned PI Controller.

3. LITERATURE SURVEY

Sr. No.	Title	Author	Year	Approach
1	Fuzzy logic control of DFIG-based wind turbine	S. Elkhadiri, P. L. Elmenzhi and P. A. Lyhyaoui	2018	This paper proposes the control of the rotor side PWM converter of a variable speed doubly fed induction generator (DFIG) based wind turbine using rotor flux oriented vector control based fuzzy logic in order to control the rotor currents.
2	A Terminal Sliding Mode Approach for the Rotor Side Converter of a DFIG-Based Wind Energy System	M. J. Morshed and A. Fekih	2018	This paper proposes a terminal sliding mode approach for the rotor side converter of a DFIG-based wind turbine. It aims at enabling the wind turbine to satisfactorily operate under unbalanced grid conditions such as voltage sags, while ensuring high performance dynamic responses in the presence of uncertainties and external disturbances.
3	Modification of DFIG's Active Power Control Loop for Speed Control Enhancement and Inertial Frequency Response	A. Ashouri-Zadeh, M. Toulabi, S. Bahrami and A. M. Ranjbar	2017	This paper proposes a fuzzy-based speed controller for the doubly fed induction generator (DFIG)-based wind turbines with the rotor speed and wind speed inputs. The controller parameters are optimized using the particle swarm optimization algorithm.
4	Mitigation of subsynchronous resonance in DFIG based wind farms using fuzzy controllers	A. Singh and S. K. Jain	2016	In this paper application of fuzzy controllers instead of PI controllers in partially rated converter has been proposed to damp out SSR oscillations.
5	Fuzzy controlled UPQC for power quality enhancement in a DFIG based grid connected wind power system	R. Bhavani, N. R. Prabha and C. Kanmani,	2015	This paper analyzes PQ problems, voltage sag and current harmonics due to the interconnection of grid connected wind turbine and also provides PQ enhancement by introducing UPQC.
6	A fuzzy sliding mode control for DFIG-based wind turbine power maximization	K. Boulâam and A. Boukhelifa	2014	This paper presents a fuzzy sliding mode control applied to reach the Maximum Power Point Tracking (MPPT) of a variable speed wind energy conversion system (VSWECS) based on a Doubly Fed Induction Generator (DFIG).
7	Stability Enhancement of DFIG-Based Offshore Wind Farm Fed to a Multi-Machine System Using a STATCOM	L. Wang and D. Truong	2013	In this paper, the simulation results of using a static synchronous compensator (STATCOM) to achieve damping improvement of an offshore wind farm (OWF) fed to a multi-machine system is presented.

S. Elkhadiri, P. L. Elmenzhi and P. A. Lyhyaoui [1] This paper proposes the control of the rotor side PWM converter of a variable speed doubly fed induction generator (DFIG) based wind turbine using rotor flux-oriented vector control based fuzzy logic in order to control the rotor currents. The fuzzy logic controllers and PI controller are used to control the rotor currents to overcome any disturbance. The simulations are developed in MATLAB Simulink.

M. J. Morshed and A. Fekih [2] This paper proposes a terminal sliding mode approach for the rotor side converter of a DFIG-based wind turbine. It aims at enabling the wind turbine to satisfactorily operate under unbalanced grid conditions such as voltage sags, while ensuring high performance dynamic responses in the presence of uncertainties and external disturbances. The controller was derived using a novel terminal sliding mode structure based on the tracking errors of the rotor currents. The controller parameters were auto-tuned using a fuzzy logic approach. The performance of the proposed approach was assessed using realistic settings including voltage sags of various depths and parameter variations. A comparison analysis with a standard SMC was also carried out.

A. Ashouri-Zadeh, M. Toulabi, S. Bahrami and A. M. Ranjbar [3] This paper proposes a fuzzy-based speed controller for the doubly fed induction generator (DFIG)-based wind turbines with the rotor speed and wind speed inputs. The controller parameters are optimized using the particle swarm optimization algorithm. To accelerate tracking the maximum power point trajectory, the conventional controller is augmented with a feed-forward compensator, which uses the wind speed input and includes a high-pass filter. The proposed combined speed controller is robust against wind measurement errors and as the accuracy of anemometers increases the speed regulation tends toward the ideal controller. The cutoff frequency of the applied filter is determined considering a compromise between the sensitivity to measurement errors and speed of regulation process. We also design an auxiliary frequency controller to equip the DFIGs with an inertial frequency response. In the proposed controller, two important constraints are taken into account: the feasible rotor speed range during the injection period, and the minimum time to recover the DFIG's speed. The impacts of the proposed controllers are evaluated through extensive time-domain simulations on an IEEE 9-bus test system using the DIgSILENT/PowerFactory software. Results confirm the effectiveness of the proposed controllers in serious transients and load disturbances.

A. Singh and S. K. Jain [4] DFIG based wind farm with Type III wind turbines are the most popular choice of wind power generation industry. Mostly, these wind farms are connected to load centers by series compensated long transmission lines. Series compensated lines offer cost effective way to evacuate large power from these wind farms. But these wind farms connected through series compensated lines may be affected by Sub Synchronous Resonance (SSR). Induction generator effect is the predominant cause of SSR in series compensated transmission lines or feeders as suggested by earlier researchers. Fuzzy logic control offers an effective way to mitigate the effect of SSR. In this paper application of fuzzy controllers instead of PI controllers in partially rated converter has been proposed to damp out SSR oscillations. First fuzzy controller parameters like number of membership functions and shape of membership functions have been studied for effectiveness of fuzzy controller for SSR control. Then fuzzy controllers for RSC, GSC and DC Link Voltage Controller have been studied and compared for their effectiveness to mitigate SSR phenomena.

R. Bhavani, N. R. Prabha and C. Kanmani, [5] Owing to fuel scarcity and environmental contamination set off by the conventional sources, renewable energy resources rule the world of power generation. Up gradation of energy production through wind farms is being encouraged now-a-days, as the wind power is dirt free, readily available renewable alternative. The integration of wind farms with power grid leads to Power Quality (PQ) issues such as voltage sag, swell, flicker, harmonics etc. Most of the industrial and commercial loads are of non-linear type which indeed the starting place of harmonics. As 70% of PQ problems are voltage sag which is one of the most severe disturbances to sensitive loads. As an outcome of the aforementioned issues both consumer sector and production sector gets affected with poor quality of power which urge PQ enhancement at its best level. Among many of custom power devices, Unified Power Quality Conditioner (UPQC) is the only device used to diminish both voltage sag and current harmonics. This paper analyzes PQ problems, voltage sag and current harmonics due to the interconnection of grid connected wind turbine and also provides PQ enhancement by introducing UPQC. To improve the performance of UPQC, a novel control strategy using Fuzzy Logic Controller (FLC) is proposed which eliminates the drawback of using fixed gains in conventional PI controller. From the simulation results, by comparing controller performance, the proposed fuzzy controlled UPQC provides effective and efficient mitigation of both voltage sag and current harmonics than the conventional PI controlled UPQC, thus making the grid connected wind power system more reliable by providing good quality of power.

K. Boulâam and A. Boukhelifa [6] This paper presents a fuzzy sliding mode control applied to reach the Maximum Power Point Tracking (MPPT) of a variable speed wind energy conversion system (VSWECS) based on a Doubly Fed Induction Generator (DFIG). The proposed control algorithm is a combination of sliding mode and fuzzy logic theories. The main controller is a sliding mode one. The fuzzy logic is used to improve the performance of the main controller, in terms of the response time and the chattering phenomenon.

L. Wang and D. Truong [7] In this paper, the simulation results of using a static synchronous compensator (STATCOM) to achieve damping improvement of an offshore wind farm (OWF) fed to a multi-machine system is presented. The operating performance of the studied OWF is simulated by an equivalent aggregated doubly-fed induction generator (DFIG) driven by an equivalent aggregated wind turbine (WT) through an eq uivalent gearbox. A PID damping controller and a hybrid PID plus fuzzy logic controller (FLC) of the proposed STATCOM are designed to contribute adequate damping characteristics to the dominant modes of the studied system under various operating conditions. A frequency-domain approach based on a linearized system model using root-loci technique and a time-domain scheme based on a nonlinear system model subject to a three-phase short-circuit fault at the connected bus are systematically performed to examine the effectiveness of the proposed control schemes. It can be concluded from the comparative simulated results that the proposed STATCOM joined with the designed hybrid PID plus FLC is shown to be superior for improving the stability of the studied system subject to a severe disturbance than the PID controller.

4. PROBLEM IDENTIFICATION

Wind power is the most reliable and quick developing among the various renewable energy sources. Wind turbines can operate both in fixed as well as variable speed operation mode. For a fixed speed operation, the generator is directly connected to grid whereas for variable speed the generator is controlled with the help of power electronic equipments. Therefore, double fed induction generator plays a vital role by operating in grid as well as in standalone mode. DFIG has attracted more attention due to its variable speed, reduced converter cost, less switching losses, higher energy efficiency and also for improved power quality. The controller in the double fed induction generator initially was implemented only with the help of a PI controller. However, the problem associated with PI controller was the tuning of gains. Therefore, PI controllers are difficult to control due to the tuning method. The problem was solved by changing the traditional PI controller with the improved Fuzzy PI controller. The advantage of using fuzzy control was to achieve a higher operation by the variation of the parameters. Fuzzy logic controller was superior over the conventional PI controller.

5. CONCLUSION

The control of a breeze vitality framework furnished with a doubly nourished enlistment generator has been portrayed in this paper. At initial, a model of the turbine and the generator are proposed. At that point, a control system dependent on fuzzy logic and PI controllers permitting free control of intensity has been exhibited. Through the reaction qualities gotten by the recreation results, the great execution is watched even within the sight of varieties of targets. Also, by looking at the controller PI and fuzzy, plainly the fuzzy control is strong against parametric varieties of the machine, gives quick intermingling, not influenced by commotion and misleading signals, and simple to actualize it in a number cruncher.

For future work to implement fuzzy PI concept in the machine side converter to achieve better performance results. extraction of the maximum power from the wind using Fuzzy logic algorithm. Try to simulate the fuzzy PI controller using improved membership function and rules to obtain a better stability of the dc link voltage.

REFERENCES

[1]. S. Elkhadiri, P. L. Elmenzhi and P. A. Lyhyaoui, "Fuzzy logic control of DFIG-based wind turbine," 2018 International Conference on Intelligent Systems and Computer Vision (ISCV), Fez, 2018, pp. 1-5.

[2]. M. J. Morshed and A. Fekih, "A Terminal Sliding Mode Approach for the Rotor Side Converter of a DFIG-Based Wind Energy System," 2018 IEEE Conference on Control Technology and Applications (CCTA), Copenhagen, 2018, pp. 1736-1740.

[3]. A. Ashouri-Zadeh, M. Toulabi, S. Bahrami and A. M. Ranjbar, "Modification of DFIG's Active Power Control Loop for Speed Control Enhancement and Inertial Frequency Response," in IEEE Transactions on Sustainable Energy, vol. 8, no. 4, pp. 1772-1782, Oct. 2017.

[4]. Singh and S. K. Jain, "Mitigation of subsynchronous resonance in DFIG based wind farms using fuzzy controllers," 2016 7th India International Conference on Power Electronics (IICPE), Patiala, 2016, pp. 1-6.

[5]. R. Bhavani, N. R. Prabha and C. Kanmani, "Fuzzy controlled UPQC for power quality enhancement in a DFIG based grid connected wind power system," 2015 International Conference on Circuits, Power and Computing Technologies [ICCPCT-2015], Nagercoil, 2015, pp. 1-7.

[6]. K. Boulâam and A. Boukhelifa, "A fuzzy sliding mode control for DFIG-based wind turbine power maximisation," 7th IET International Conference on Power Electronics, Machines and Drives (PEMD 2014), Manchester, 2014, pp. 1-6.

[7]. L. Wang and D. Truong, "Stability Enhancement of DFIG-Based Offshore Wind Farm Fed to a Multi-Machine System Using a STATCOM," in IEEE Transactions on Power Systems, vol. 28, no. 3, pp. 2882-2889, Aug. 2013.