COMPARATIVE STUDY OF CLOSED LOOP CONTROL DFIG BY USING FUZZY LOGIC AND PI CONTROLLERS

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Abstract

Doubly-fed induction generator (DFIG), maybe a producing rule broadly utilized in wind turbines. By utilizing the converter to control the rotor streams, it is conceivable to alter the dynamic and receptive control nourished to the framework from the stator freely of the generator's turning speed. a doubly-fed Induction machine a wound-rotor doubly-fed electric machine and has a few focal points over a customary Induction machine in wind control applications. To begin with, as the rotor circuit is controlled by a control hardware converter, the Induction generator can both moment and send out responsive control. This has imperative results for control framework steadiness and permits the machine to bolster the network amid extreme voltage unsettling influences. Moment, the control of the rotor voltages and streams empowers the Induction machine to stay synchronized with the network whereas the wind turbine speed changes. A variable-speed wind turbine utilizes the accessible wind asset more effectively than a fixed-speed wind turbine, particularly amid light wind conditions. Third, the taken toll of the converter is moo when compared with other variable speed arrangements since as it were a division of the mechanical control is encouraged to the lattice through the converter, the rest being encouraged to the lattice specifically from the stator The fluffy rationale controller is a set of etymological control rules related to the double concepts of fluffy suggestion and the compositional run the show of deduction. The FLC gives a calculation that can change over the phonetic control methodology based on master information into a programmed control methodology. The execution of such control comprises interpreting the input factors to a dialect like positive huge, zero, negative little, etc., and building up control rules so that the choice prepare can create the fitting yields. Fluffy control (FC) utilizing etymological data has a few points of interest such as vigor, model-free, all-inclusive estimation hypothesis, and rules-based calculation. This paper points to compare the execution of the Proportional-Integral (PI) controller and Fluffy rationale controller for vector control of the rotor side converter (RSC). The objective is to supply free control of stator dynamic and responsive control, as well as ideal speed following for the greatest vitality capture. A vector control conspire for the network side converter (GSC) will also be inspected, to supply an autonomous control of slip dynamic and receptive control traded between the lattice and GSC. The comes about of this comparison will be utilized to decide which of the two controllers is more reasonable for vector control of the RSC and GSC. The study will moreover give an understanding into the potential of both PI and Fluffy rationale controllers in giving autonomous control of stator dynamic and receptive control, as well as ideal speed following for most extreme vitality capture. This control technique is executed in MATLAB/SIMULINK environment.

Keywords: —MPPT, DFIG, Rotor Side Converter(RSC), Grid Side Converter(GSC), PI Controllers, Fuzzy logic control, Vector control, Wind Energy Conversion System.

Ⅰ. INTRODUCTION

1.1 Background and Motivation

Investigating in wind control era frameworks is booming due to the expanded request for renewable vitality sources. The double-fed Induction generator (DFIG) is broadly utilized in wind turbines due to its preferences over ordinary Induction machines, such as controlling rotor streams and bringing in and sending out receptive control. Control of the rotor voltages and streams empowers the Induction machine to stay synchronized with the network whereas the wind turbine speed changes. This leads to more effective vitality capture. The DFIG innovation empowers the turbine to capture vitality from the wind and nourish it into the lattice. This gives a dependable source of renewable vitality, which makes a difference to decrease dependence on fossil powers and relieve the impacts of climate alteration. The motivation for this term paper is to compare two control methodologies, fluffy rationale, and PI controllers, for DFIG used in wind turbines. In spite of the fact that PI control could be a well-known strategy for DFIG control, fluffy rationale control has a few focal points, such as vigor and model-free characteristics, making it a promising choice for DFIG control methodologies. This investigation gives an in-depth investigation of both control strategies' execution in the autonomous control of stator dynamic and receptive control, ideal speed following, and resistance to unsettling influences. This inquiry about will contribute to the enhancement of wind control era frameworks and advance the advancement of more effective and solid control procedures for DFIG. The ponder moreover gives a comprehensive comparison of the two control procedures, highlighting the preferences and impediments of each. The comes about of this inquiry about will be valuable for future applications of DFIGs in wind control era frameworks.

1.2 Problem Statement

The issue tended to in this term paper is the comparison of two control methodologies, fluffy rationale, and PI controllers, for a doubly-fed Induction generator (DFIG) utilized in wind turbines. The objective is to attain free control of stator dynamic and responsive control, ideal speed following, and resistance to unsettling influences. To decide which control technique is more fitting for DFIG control procedures in wind control applications, this ponder compares both control methodologies to recognize their qualities and shortcomings.

1.3 Investigate Objective

Giving a point-by-point understanding of the DFIG framework, its preferences over ordinary Induction machines, and the requirement for effective control procedures in wind control applications. And creating a vector control conspire for the rotor side converter (RSC) that gives free control of stator dynamic and responsive control and ideal speed following for most extreme vitality capture. Executing a vector control plot for the network side converter (GSC) that gives autonomous control of slip control and responsive control traded between the framework and GSC. Comparison of fluffy rationale and PI controllers execution in terms of free control of stator dynamic and receptive control, ideal speed following, and resistance to disturbances. To assess the viability of the proposed fluffy rationale control strategy utilizing a shrewdly fluffy induction system with master knowledge. To approve the proposed control procedure by reenactment and comparison of reenactment comes about of fluffy rationale and PI controllers utilizing MATLAB/SIMULINK environment. This investigation provides a comprehensive investigation and comparison of fluffy rationale and PI controllers for DFIG control methodologies in wind control applications. The extreme objective is to create a more effective and solid control procedure for DFIG-based wind turbines. This methodology ought to be able to decrease control misfortunes and progress the by and large vitality yield of the wind turbines. Also, the procedure ought to too be able to decrease the requirement for complex and costly control hardware frameworks.

1.4 Structure of Paper

The rest of the paper is organized as follows. Principles of PI and Fuzzy control strategies for DFIG Control are discussed in Section II. Section III gives a dynamic mathematical model of the wind turbine system. Modeling of the DFIG system for its stator and rotor equations is discussed in Section IV and Section V consists of the Vector control strategy of the DFIG. The Fuzzy logic control strategy for the control of DFIG is given in Section VI. Simulation Results for the considered parameters are presented in Section VII, Conclusion of the paper is stated in Section VIII.

Ⅱ. Principles of DFIG Control Strategies

The control framework may be a pivotal issue for the wind vitality transformation framework (WECS). It maximizes the extricated control from the wind through all the components. It moreover guarantees that the conveyed control to the network complies with the interconnection prerequisites. The control procedure is connected to distinctive parts of the doubly-fed Induction generator-based wind vitality change framework (WECS) and they have distinctive points. Numerous numbers of diverse control strategies have been developed to control wind vitality change frameworks. The foremost broadly utilized strategy of controlling converters is utilizing PI controllers. However, PI controller has the same major issues: unreliable conditions within the precise show, and erratic behavior of a few framework details, such as wind speed, varieties in reference values of required control, and concurrent changes in these parameters, which makes controller parameter direction so hard [1],[2]. The reason for this paper is to control Active, reactive, and dc-link voltage employing a fluffy controller. Utilizing fluffy control, we are able to deliver controller yields that are more solid since the impact of other parameters such as commotion and occasions due to a wide extent of control zones can be considered. Additionally, the control of parameters can be done more effortlessly without the need for a numerical show of the framework and by fair utilizing the full operation and behavior of the framework [1].

2.2 PI Control Strategy

A PI controller (proportional-integral controller) can be utilized in a closed-loop framework for a Double-Fed Induction Generator (DFIG) to control the generator's electrical control yield. DFIGs are regularly utilized in wind turbines, where the control yield should be controlled to preserve a steady frequency within the electric grid. The PI controller can offer assistance to the generator's electrical control yield by shifting the current through the rotor winding. This in turn influences the generator's torque. The PI controller has two components: corresponding and integral. The relative component changes the yield based on the contrast between the required setpoint and the current measured esteem. Necessarily components alter the yield based on the collected error over time, which disposes of steady-state errors. The PI controller's yield alters the voltage connected to the rotor winding. This voltage can be controlled using a control hardware converter. The converter alters the voltage to preserve the required rotor current, which controls the generator's control yield. In outline, a PI controller can be utilized in a closed-loop framework for a DFIG to control the generator's electrical control yield by setting the voltage connected to the rotor winding. The corresponding component modifies the yield based on the current blunder, whereas the fundamental component alters the yield based on the gathered blunder over time. This comes about in way better framework control.

2.3 Limitations of PI Control

PI control can overshoot the desired set point, which can harm the system. I control can have a slow transient response time, which can cause delays in the system. PI control can have limited accuracy in situations where system parameters change constantly. PI control requires proper tuning to optimize system performance, and this can be a complex process that requires a deep understanding of the system.

2.4 Fuzzy control

Zadeh introduced fuzzy logic controllers in 1965. Following that, Mamdani presented fuzzy logic-based controller concepts in 1974 [3]. The main concept behind fuzzy logic is studying analog inputs in terms of logical variables that can take continuous values between 0 and 1. On many occasions, fuzzy logic control is considered more effective than conventional control, especially in large-scale systems. It is usually adopted in electronic systems to enhance system performance by minimizing fluctuations in system outputs [4, 5]. Fuzzy logic is mainly based on the element (x) and the associated membership function (μ) which determines the percentage of this element belonging to the fuzzy set [6]. A general fuzzy set (A) is represented by a membership function μA and the element which can have any value in the range (X) as represented in the equation below. The membership function (μA) is used to determine the degree of membership of the element (x) in the fuzzy set (A). The membership function can be represented graphically or numerically as a function of the element. The participation work can at that point be utilized to decide the yield of the fluffy rationale framework. The yield of the fluffy rationale framework is decided by the degree of participation of the component within the fluffy set. This yield can then be utilized to form choices or take essential activities.

$$A = \{(x, \mu A(x)) | x \in X\}$$

Multiple variables can belong to the same subset (A) or different subsets (A and B) but with different percentages. The individuals of these subsets speak to the values of each variable. The enrollment capacities are made with certain shapes that are characterized to a particular extent. Fig. 2.1 speaks to a case of a triangular participation work that includes a range of (-E, E).

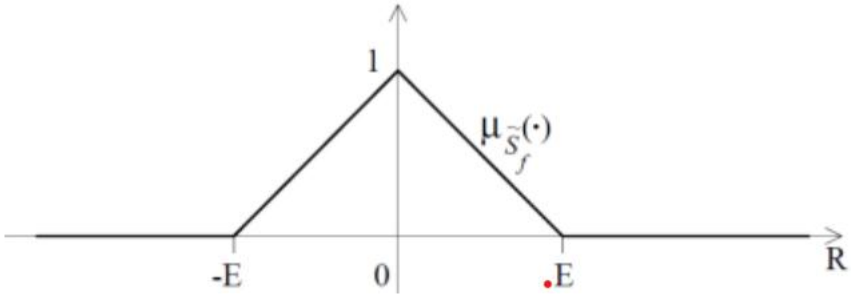


Fig 2.1 A Triangular Membership Function

At $x = 0$, the membership function contains an esteem of 1 which outline that this esteem has a place in this enrollment work with a rate of 100%. On the other hand, at x =E/2, the enrollment encompasses esteem of 0.5 which suggests that there's a chance of 50% in which this variable can have a place in this membership function [6]. The range between E2 is the region of instability. This implies that the values of x between and E2 have a likelihood of having a place in this enrollment work that goes from 100% to 0%. This zone of vulnerability is known as the fluffy locale. The measure of the fluffy locale can be balanced agreeing to the application. A smaller fluffy locale will give more exact comes about, whereas a bigger locale will increment the adaptability of the framework. When designing a fuzzy logic control, we should pass through three phases:

1)Fuzzification,

2) Fuzzy rule base and

3) Defuzzification.

The former phase includes designing membership functions and selecting the proper range. The middle phase represents the rules that link the inputs to the outputs, and they are squared of the number of the designed memberships. The latter phase transforms the generated fuzzy value into a numerical value. For example, the middle phase is composed of "if-then" rules of the form: if (x is A) and (y is B), then (z is C). This is an example of fuzzy logic, which is a form of artificial intelligence that uses imprecise data to process and make decisions. Fuzzy logic helps machines to interpret real-world situations more accurately and can be used to solve problems that require complex decisions based on incomplete or uncertain information. Fuzzy logic can be applied to a wide range of tasks, from controlling machines to decision-making. It can also be used to improve the accuracy of predictive analytics models. A general fuzzy logic block diagram is represented in Fig. 2.2

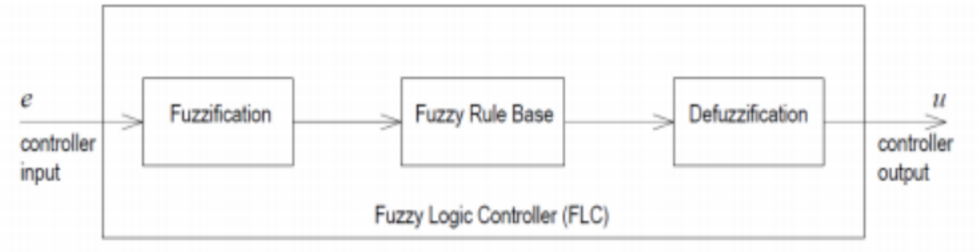


Fig 2.2 The Three components of the fuzzy logic controller

Ⅲ.Dynamic Mathematical Model

3.1 Introduction to DFIG

Double-fed Induction generator (DFIG) is one of the foremost Well known wind turbines which incorporates an Induction generator With a slip ring, a back-to-back voltage source converter, and a Common DC-link capacitor. Control electronic converters have Two primary parts; the lattice side converter (GSC) and the rotor side converter (RSC). This converter (RSC) uses three-phase stator winding that's specifically associated with the lattice whereas the three-phase rotor winding is associated with the lattice by slip rings and brushes through a control Converter. The back-to-back control converter has full Controllability of the framework. It can be utilized to direct the control stream between two vitality sources, such as renewable vitality sources and the power network. The converter can too control the voltage and recurrence of the vitality, permitting a consistent vitality exchange. This makes a difference to guarantee a steady control framework and encourages the integration of renewable vitality sources into the network. It moreover guarantees that the control delivered is of the most elevated quality and can be utilized dependably.

3.2 Mathematical Model of Wind Turbine

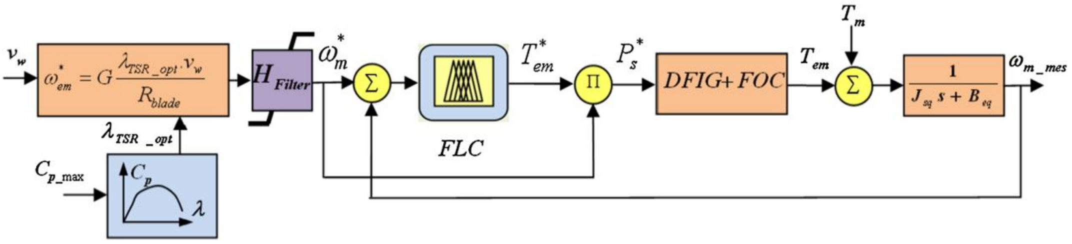


Fig 3.1 Block diagram for speed control using a fuzzy logic controller

The division of the control within the wind extricated by the turbine and indicated by Pt is given as:

$$P_t = 1/2\ \pi\rho R^2_{blade} v^3_w C_p(\lambda_{TSR}, \beta) \qquad — 3.1$$

The effectiveness coefficient is approximated by employing a nonlinear work since it gives more exact comes about and is faster in simulation, it may be a work of the pitch point signified by β, and the tip speed proportion (TSR) signified by $\boldsymbol{\lambda_{TSR}}$, which is given as:

$$\lambda_{TSR} = \frac{R_{Blade} W_t}{V_w} \qquad — 3.2$$

The relationship between $\boldsymbol{\lambda_{TSR}}$**,** and Cp for distinctive b is displayed in Fig. 2 and given by the following relation:

$$Cp(\lambda_{TS}, \beta) = 0.240\left(\frac{116}{\lambda i} - 0.4\beta - 5\right)e^{\frac{-12.5}{\lambda i}} \qquad — 3.3 \qquad \frac{1}{\lambda i} = \left[\left(\frac{1}{\lambda_{TSR} + 0.08\beta}\right) - \left(\frac{0.035}{\beta^3 + 1}\right)\right] \qquad — 3.4$$

For the turbine operation when there's a plausibility to control TSR, the pitch angle is kept at zero. The most extreme esteem of the efficiency coefficient can reach 16/27 ≈ 0.593 which is called the Betz restrain (Li and Chen 2006). The driving torque of the turbine is characterized by:

$$T_t = \frac{P_t}{W_t} \qquad —— 3.5$$

IV. MODELING OF THE DFIG

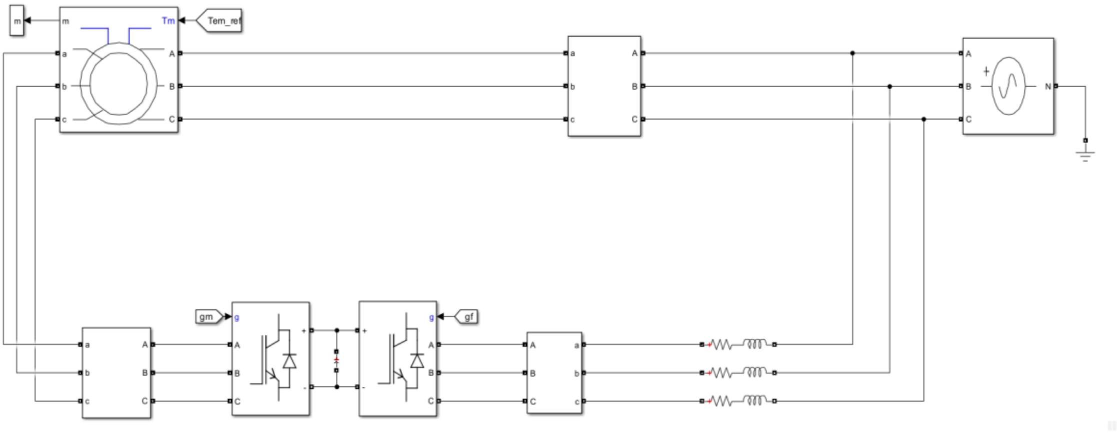


Fig-4.1 Modelling diagram of Closed loop DFIG

The common model of the DFIG is continued as takes after: The conditions of the stator and rotor voltages within the d-q outline individually are given by:

$$V_{ds} = R_s I_{ds} + \frac{d}{dt}\psi_{ds} - \omega_s \psi_{qs} \qquad —4.1$$

$$V_{qs} = R_s I_{qs} + \frac{d}{dt}\psi_{qs} - \omega_s \psi_{ds} \qquad —4.2$$

$$V_{dr} = R_r I_{dr} + \frac{d}{dt}\psi_{dr} - \omega_r \psi_{qr} \qquad —4.3$$

$$V_{qr} = R_r I_{qr} + \frac{d}{dt}\psi_{qr} - \omega_r \psi_{dr} \qquad —4.4$$

The stator and rotor flux linkage conditions within the d-q outline separately are given by:

$$\psi_{ds} = L_s I_{ds} + M I_{dr} \qquad —4.5$$

$$\psi_{qs} = L_s I_{qs} + M I_{qr} \quad \text{—4.6}$$

$$\psi_{dr} = L_r I_{dr} + M I_{ds} \quad \text{—4.7}$$

$$\psi_{qr} = L_r I_{qr} + M I_{qs} \quad \text{—4.8}$$

The EM torque generated by the DFIG is given by:

$$T_{em} = \frac{pM}{L_s}(\psi_{ds} I_{qr} - \psi_{qs} I_{dr}) \quad \text{—4.9}$$

R_r , R_s : Rotor and Stator phase resistances.

L_r , L_s : Rotor and Stator phase inductances.

: the mutual inductances.

: Machine pole pairs.

V. VECTOR CONTROL STRATEGY

Hasse and Blaschke created this strategy by drawing motivation from DC engine drives. This strategy isolates flux and torque control [8]. DFIG is progressively utilizing vector control due to its effectiveness in controlling. Vector control permits for made strides execution, decreased torque swell, and quick energetic reaction. Vector control moreover dispenses with the require for a slip emolument calculation and can viably handle a wide run of stack necessities. In expansion, vector control is cost-effective due to its moo component check. Vector control has the potential to create the framework more solid and diminish upkeep costs. It moreover permits for higher framework proficiency and progressed control quality. Vector control can too give superior framework solidness, progressed energetic reaction, and smoother operation. Vector control is subsequently a awesome choice for complex engine control frameworks.

Agreeing to the proposed procedure, the stator flux is adjusted with the d-axis:

$$\varphi_{sd} = \varphi_s \quad \text{—5.1}$$

$$\varphi_{sq} = 0 \quad \text{—5.2}$$

So agreeing to condition (4.9), the electromagnetic torque is given by:

$$T_{em} = -p\frac{M}{L_s}(\varphi_{sd} I_{rq}) \quad \text{—5.3}$$

The equations of the direct and quadratic stator currents individually:

$$I_{sd} = -\frac{M}{L_s} I_{rd} + \frac{\varphi_s}{L_s} \quad \text{—5.4}$$

Accepting that the framework is steady and the voltage drop of the stator resistance Rs is dismissed [9], [10]:

$$V_{ds} = 0 \quad \text{—5.5}$$

Hence, by situating the coordinate axis with the stator flux, the voltage is adjusted with the axis in quadrature. The stator Active and reactive powers can at that point be composed as takes after:

$$P_s = V_s I_{sq} \quad \text{—5.6}$$

$$Q_s = V_s I_{sd} \quad \text{—5.7}$$

To get the expressions of the powers as a work of the rotor streams, the streams within the two past conditions are supplanted by their expressions in conditions (5.6) and (5.7):

$$P_s = -V_s \frac{M}{L_s} I_{rq} \quad \text{-—5.8}$$

$$Q_s = -V_s \frac{M}{L_s} I_{rd} + \frac{V_s^2}{L_s \omega_s} \quad —\!—5.9$$

The final conditions appear that the active and receptive powers might be controlled by means of rotor streams. The dynamic control can be controlled by the current on the quadratic pivot, whereas the responsive control can be controlled by the current on the coordinate pivot. In this way, the rotor voltages within the d-q axis can be composed as takes after

$$V_{rd} = \left(\frac{R_r L_s + \sigma L_s L_r S}{M V_s}\right)\left(Q_s - \frac{V_s^2}{L_s \omega_s}\right) - \omega_r L_r \sigma I_{rq} \quad —5.10$$

$$V_{rq} = \left(\frac{R_r L_s + \sigma L_s L_r S}{M V_s}\right) P_s + \omega_r L_r \sigma I_{rd} + \omega_r \frac{M V_s}{L_s \omega_s} \quad —5.1$$

: the coefficient of Leakage, it is given by :

$$\sigma = 1 - \frac{M^2}{L_s L_r} \quad —5.12$$

The system transfer function is defined by ignoring the coupling terms $-\omega_r L_r \sigma I_{rq}$ and $\omega_r L_r \sigma I_{rd} + \omega_r \frac{M V_s}{L_s \omega_s}$. At that point including these terms to the yield.

VI. Fuzzy Control Strategy

Fluffy rationale controllers (FLCs) are a sort of control framework that utilize fluffy rationale to reason approximately loose or questionable data. FLCs can utilize a set of fluffy rules to inexact the behavior of a complex framework. This makes them valuable for controlling complex forms that are troublesome to demonstrate numerically. FLCs are moreover utilized to imitate human decision-making forms. They are especially valuable for assignments where there are different goals or questionable inputs. They can too be utilized to optimize complex frameworks in real-time.FLCs are able to handle non-linear, questionable, and complex frameworks that are troublesome to demonstrate numerically. They can be effectively executed and tuned utilizing basic rules, and their execution can be progressed with extra rules or fluffy sets.

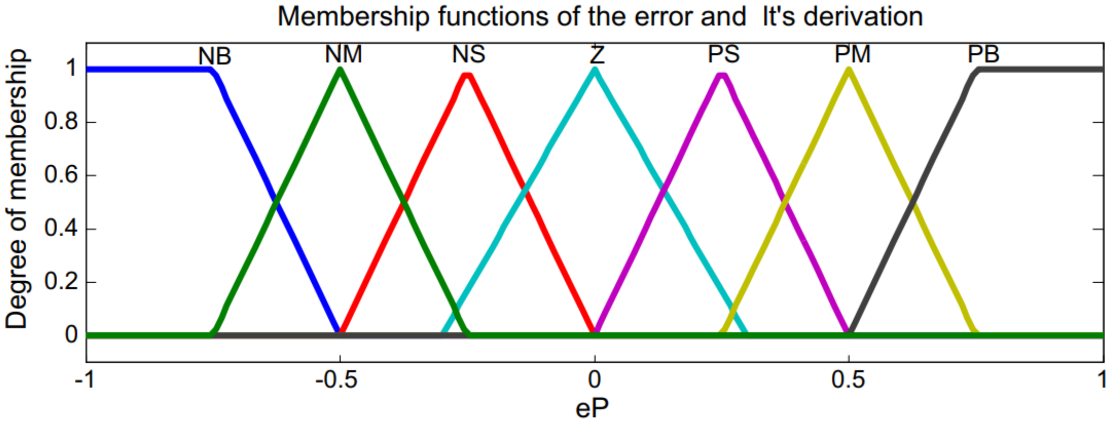
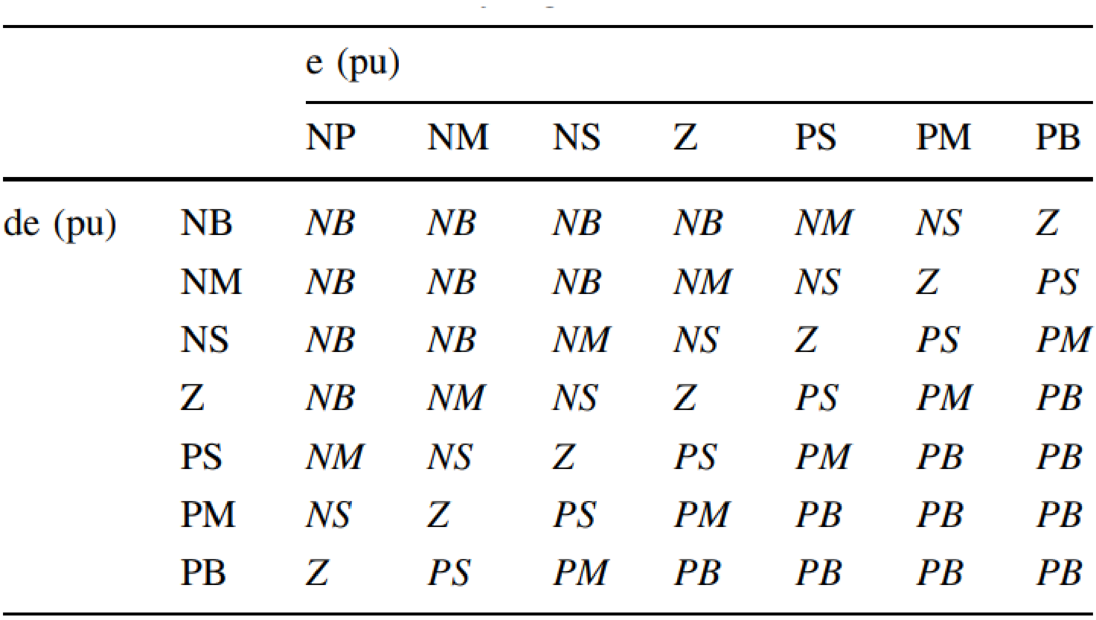


Fig 4.1 Membership functions for the outputs and inputs of the Fluffy controller.

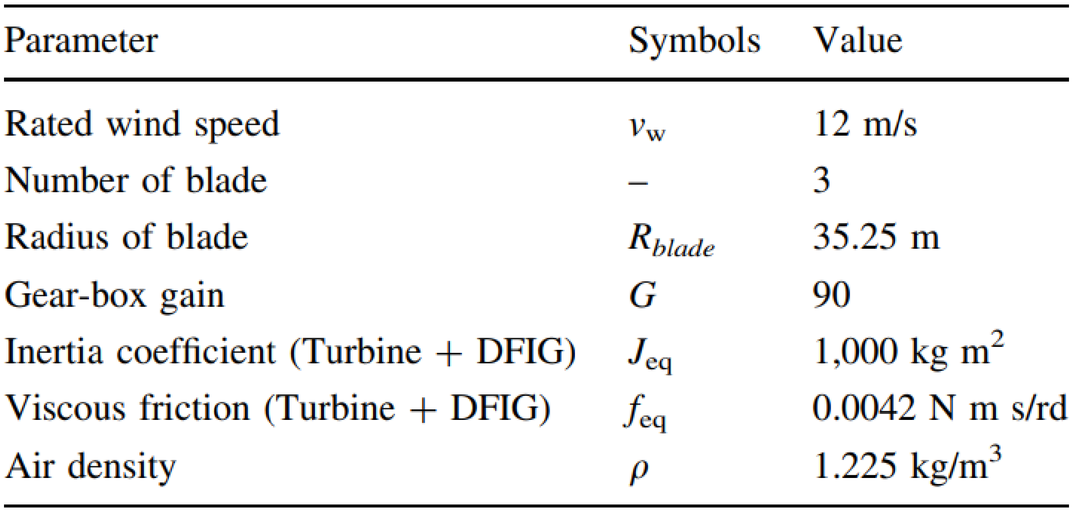


		e (pu)						
		NP	NM	NS	Z	PS	PM	PB
de (pu)	NB	*NB*	*NB*	*NB*	*NB*	*NM*	*NS*	*Z*
	NM	*NB*	*NB*	*NB*	*NM*	*NS*	*Z*	*PS*
	NS	*NB*	*NB*	*NM*	*NS*	*Z*	*PS*	*PM*
	Z	*NB*	*NM*	*NS*	*Z*	*PS*	*PM*	*PB*
	PS	*NM*	*NS*	*Z*	*PS*	*PM*	*PB*	*PB*
	PM	*NS*	*Z*	*PS*	*PM*	*PB*	*PB*	*PB*
	PB	*Z*	*PS*	*PM*	*PB*	*PB*	*PB*	*PB*

Fig 4.2 Rule base for fluffy logic controller

Z = zero, PS = Positive Little, PM = Positive Medium, PB = Positive Huge, NS = Negative little, NM = Negative Medium, NB = Negative Enormous, The universe of talk of all the factors is communicated in per unit values. There are seven MFs for the inputs and the yield signals. All MFs are symmetrical for positive and negative values of the factors. Fluffy control run the show database comprises of arrangement if-and-then fluffy rationale condition sentences. Table 1 appears the comparing run the show table for the fluffy controller, the plan of these rules is based on subjective information, found from broad Simulation tests.

Ⅶ. SIMULATION PARAMETERS



Parameter	Symbols	Value
Rated wind speed	v_w	12 m/s
Number of blade	–	3
Radius of blade	R_{blade}	35.25 m
Gear-box gain	G	90
Inertia coefficient (Turbine + DFIG)	J_{eq}	1,000 kg m^2
Viscous friction (Turbine + DFIG)	f_{eq}	0.0042 N m s/rd
Air density	ρ	1.225 kg/m^3

Table 7.1 Operational Parameter of the Wind turbine

Parameter	Symbols	Value
Rated active power	P_n	1.5 MW
Rated stator voltage (line to line)	V_s	690 V
Rated frequency	f	50 V
Rated DC-link voltage	V_{DC}	1,200 V
Number of poles	$2p$	4
Stator resistance	R_s	0.012 Ω
Rotor resistance	R_r	0.021 Ω
Stator leakage inductance	L_s	0.0137 H
Rotor leakage inductance	L_r	0.0136 H
Magnetizing inductance	M	0.0135 H
DC-link capacitance	C_{DC}	0.0044 F
Filter resistance	R_f	0.012 Ω
Filter inductance	L_f	0.005 H

*Table **7**.2 System Parameters of the DFIG*

VIII. SIMULATION RESULTS

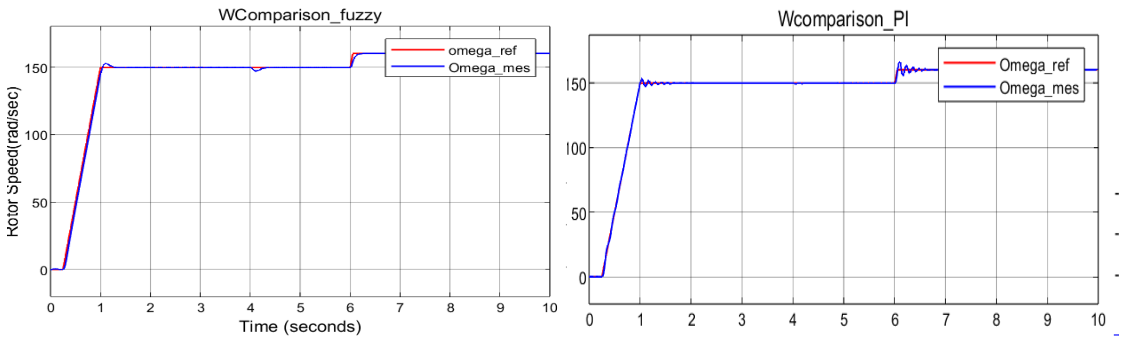


Fig 7.1 Rotor speed of DFIG machine

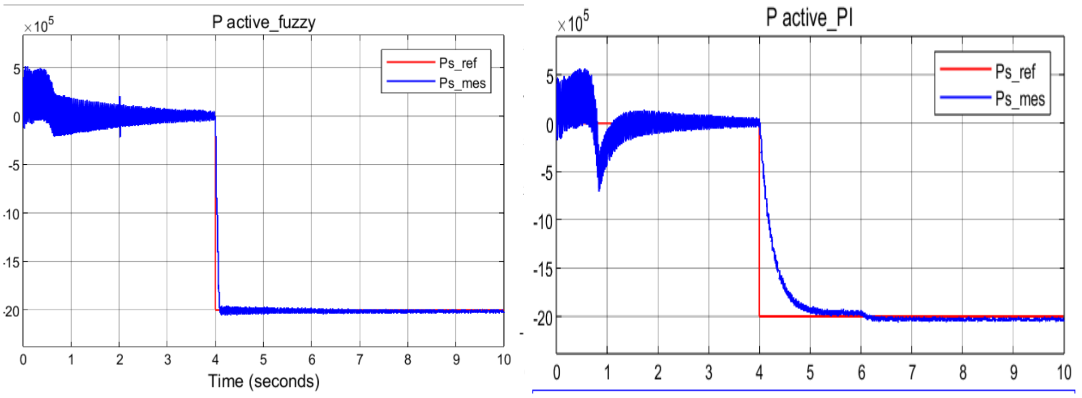


Fig 7.2 Active power of DFIG machine

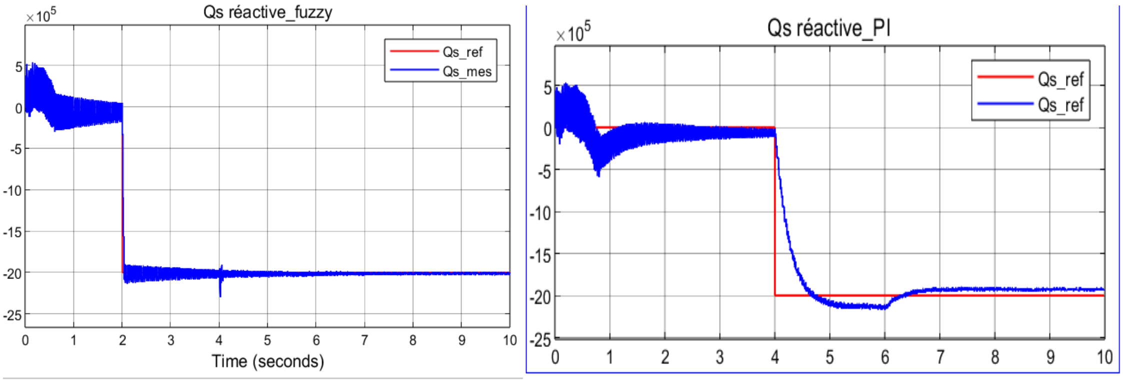


Fig 7.3 Reactive power of DFIG machine

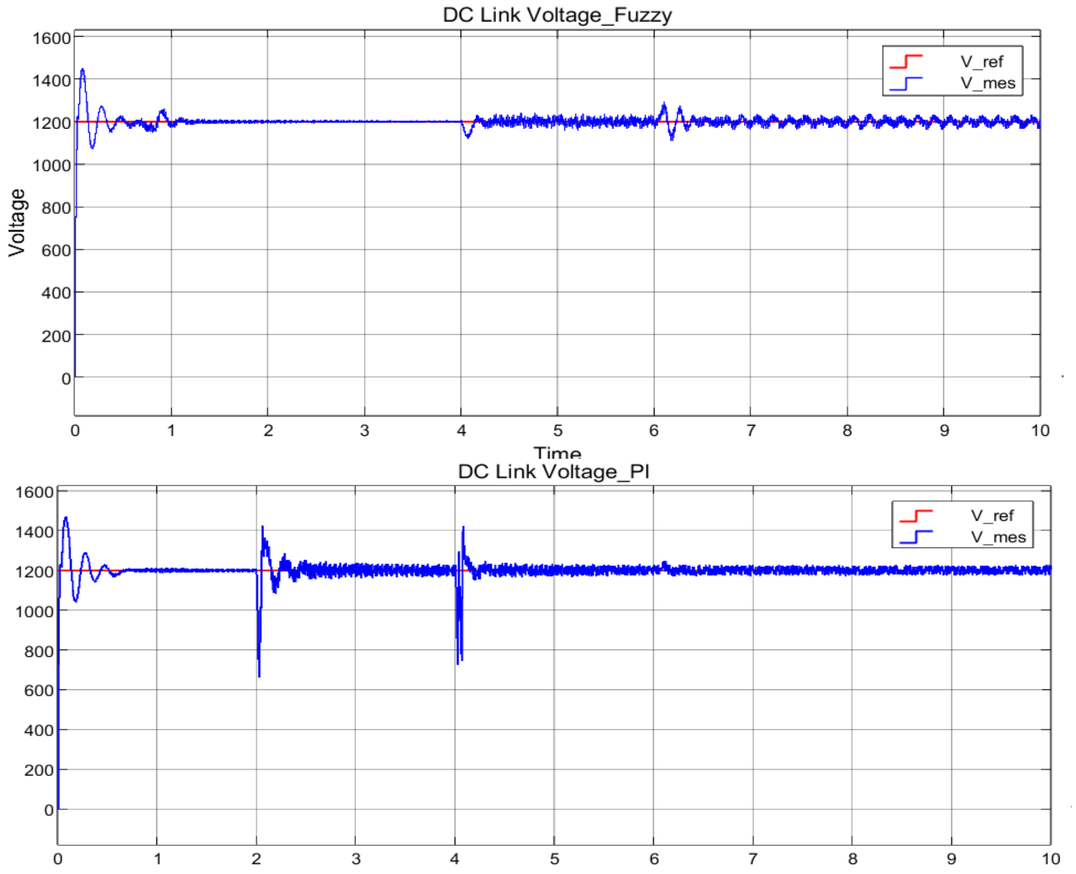


Fig 7.4 DC Link Voltages

IX. CONCLUSION

The comparative study of closed-loop control of DFIG by using fuzzy logic and PI controllers was carried out to determine the performance of both control strategies in wind power applications. The study aimed to achieve independent control of stator active and reactive power, optimal speed tracking, and resistance to disturbances. Based on the results obtained, it was concluded that both PI and fuzzy logic controllers are suitable for vector control of DFIG, but fuzzy logic controllers provide more robust and accurate control than PI controllers. Fuzzy logic controllers can handle uncertainties and nonlinearities in the control system, making them more suitable for wind power applications. Overall, this study provides insight into the potential of both PI and fuzzy logic controllers in providing independent control of stator active and reactive power and optimal speed tracking for maximum energy capture in wind power generation systems. The findings of this study could be useful for future research in developing more efficient and reliable control strategies for DFIG.

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