Backstepping approach for the control of the double-fed asynchronous generator in a wind power system

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Article Info

ABSTRACT

This paper aims to model and control the dual-fed asynchronous generator (DFIG). The modeling and vector control were simulated using MATLAB, followed by the application of the Backstepping control strategy. A comparative study between two DFIG control strategies, fuzzy logic control (FLC) and Backstepping control, was conducted. The results for the Backstepping approach are discussed and compared with FLC, highlighting that the Backstepping technique addresses robustness issues regarding variations in operating conditions and internal parameters. Both control strategies are applied to a wind turbine system, and the simulation results and robustness tests are analyzed.

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1. INTRODUCTION

Wind power, with its capacity to meet global energy needs and reduce greenhouse gas emissions, is vital for the transition to sustainable energy sources. Efficient regulation of double-fed induction generators (DFIGs) is key to optimizing wind energy output and maintaining grid stability. A literature review highlights significant contributions in this field. Various control methods for DFIGs, such as the Backstepping approach and fuzzy logic control (FLC), have been examined. Studies [1]-[5] have shown the benefits of the Backstepping approach in enhancing system performance and stability. Other research [6]-[10] has demonstrated the adaptability and flexibility of fuzzy logic in controlling DFIGs in wind farms. However, previous studies have not explicitly compared the influence of Backstepping and fuzzy logic on specific performance metrics under varying operating conditions. To address these gaps, our research analyzes the use of the Backstepping approach and fuzzy logic for controlling DFIGs in wind power systems. By comparing these methods and evaluating their performance, we aim to identify weaknesses in existing literature and suggest improvements. Our research integrates advanced control methods to push the field of wind energy forward. We provide an in-depth analysis of the Backstepping and fuzzy logic approaches to DFIG control, aiming to inform the design and implementation of future wind energy systems for a more sustainable and efficient energy transition. This paper presents a detailed Backstepping-based control approach for DFIGs used in wind power systems. Previ-

ous work by Ladide *et al.* [11], Hihi and Rahmani [12], and Soulouh *et al.* [13] has enabled us to design an innovative control method that improves DFIG performance while ensuring stability. Additionally, we conduct a detailed analysis of the Backstepping approach and FLC, highlighting the advantages and disadvantages of each method. Extensive simulations, building on research by Moumani *et al.* [14] and Nadour *et al.* [15], confirm the effectiveness of our control method.

Finally, we discuss the practical implications of our results and their potential impact on further developing wind energy systems. Our method aims to advance ongoing research by offering practical and innovative solutions for controlling DFIGs in current wind power systems. The following sections will detail our research approach, results, and conclusions, emphasizing the relevance and importance of our work in wind system control.

2.   METHOD

This section outlines the methodology for modeling and controlling a DFIG in a wind energy system. While previous studies have explored these systems, they have not sufficiently addressed the robustness of control strategies given their inherent non-linearity. We sequentially model the wind turbine, the dual-supply asynchronous generator, and the simulation, including technical details, parameters, and simulation schemes (Jones *et al.* [1], Smith *et al.* [2]). Due to its effectiveness in complex dynamic system modeling, MATLAB/Simulink was utilized. We found that the nonlinear Backstepping controller effectively regulates reactive and active powers. FLC demonstrated flexibility in adapting to operational and environmental changes Wang *et al.* [8]. Our results correlate with Chen *et al.* [7], who highlighted the comprehensive nature of generator control algorithms, focusing on the underlying theoretical principles. Parametric changes on mutual inductance L_m and rotor resistance R_r were conducted to evaluate control system stability, validating our simulation results (Huang). Despite these findings, further in-depth studies are needed to confirm our approach, especially regarding parametric variations. We recommend consulting supplementary references for a thorough confirmation. Our study demonstrates that both Backstepping and fuzzy control methods are robust, with the system exposed to active and reactive power levels to monitor regulator behavior. Future research should explore these methods in more diverse operational scenarios to enhance the reliability of control strategies.

3.   MODELLING THE WIND ENERGY SYSTEM

The wind energy system is made up of various crucial parts that make sure it works. These consist of a machine-side converter, a doubly-fed asynchronous generator (DFIG), a gearbox, and a turbine. The energy conversion process starts when wind energy is captured by the turbine and then sent to the DFIG to be converted into electrical energy. A wind turbine with three blades of length R that are powered by a generator is employed in the system under study. A gain multiplier G is included in this arrangement to increase the generated power.

3.1.   Wind modelling

The initial phase of establishing a wind power project involves meticulously choosing the site's geographic location. It is necessary to closely examine the wind characteristics since the power produced by a wind energy system is directly related to the cube of the wind speed. To gain an in-depth understanding of the particularities of a given site, it is essential to collect data on wind direction and speed over an extended period [4]. In our study, we used a specific wind model [5] whose expression is in (1).

$$v(t) = 8 + 0.2 * sin(0.1047.t) + 0.2 * sin(3.6645.t) + 2.sin(0.2665.t) \tag{1}$$

This mathematical model enabled us to analyse in greater detail the fluctuations in wind speed over time at the site studied, for a detailed description of this part, please refer to our previous article [16].

3.2.   Turbine modelling

The part of the system responsible for converting wind energy from kinetic to mechanical is the wind turbine. When wind hits the turbine blades at a particular speed v, it generates mechanical energy on the turbine shaft, making the blades spin. The aerodynamic power harnessed by the turbine rotor is expressed by (1).

$$P_t = \frac{1}{2}.C_p(\lambda, \beta).\rho.S.v^3 \tag{2}$$

Typically, the power coefficient is shown as a function of the tip speed ratio λ in relation to the angle β, which is the angle formed between the rotation direction and the chord line of the blade section. The tip speed ratio of a wind turbine is explained as (3):

$$\lambda = \frac{u}{v} = \frac{\Omega_t . R}{v} \tag{3}$$

where: ρ: the density of the air, λ: relative speed is the ratio of wind speed to linear speed at the turbine blade tips, Ω_t: the turbine's rotational speed, R: the blade's length, S: the circle that the turbine sweeps, v: the wind speed and C_p: the coefficient of power, for a detailed description of this part, please refer to our previous article [16].

4. DFIG MODELLING

There is a plethora of research on the modeling of the doubly-fed induction generator (DFIG) in the literature [1]-[3]. The mathematical model of the DFIG is quite simple in design, but it is remarkably sophisticated. Its nonlinear and multivariable structure and the interplay of electrical, magnetic, and mechanical events during operation [17] are the causes of this complexity. One feature of the DFIG model is that it generates differential equations whose coefficients change over time in response to the rotor's position inside a fixed three-phase reference frame that is linked to the stator. This raises the machine's modeling complexity even more [4]. For a detailed description of this part, please refer to our previous article [18].

4.1. Vector control of DFIG

By manipulating the rotor flux of the DFIG, it becomes possible to regulate both active and reactive power. This approach guarantees that the armature reaction flux and rotor flux maintain a perpendicular relationship. To autonomously regulate the stator power [19], it becomes essential to independently control the transverse voltages of the rotor and armature by introducing compensation terms, thus attaining a decoupled control mode [20]. By making adjustments from (23) to (18), the rotor voltages can be redefined. The following Figure 1 shows the regulated system's block diagram. For a detailed description of this part, please refer to our previous article [21].
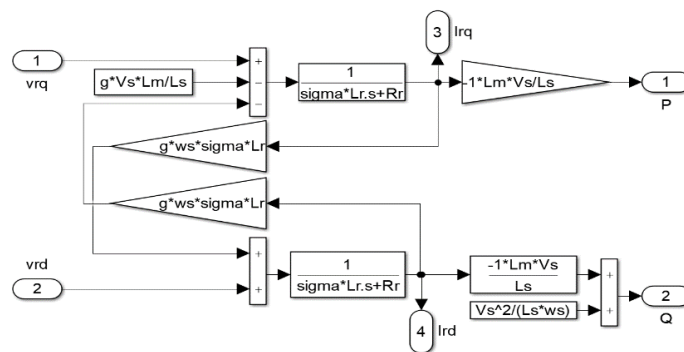

Figure 1. Block schematic of the regulated system

5. THE PRINCIPLE OF THE BACKSTEPPING COMMAND

The fundamental principle of Backstepping control is to reorganise closed-loop systems into subsets of lower-order subsystems, each of which is stabilised according to the Lyapunov criterion. This approach gives these systems robustness properties and ensures their overall asymptotic stability. In other words, it is a multi-stage process in which, at each stage [22], a virtual control is generated to ensure that the system converges towards the desired equilibrium state. This convergence is achieved progressively through the use of Lyapunov functions that ensure step-by-step stabilisation.

5.1. The control of non-linear systems is based on two Lyapunov approaches

Lyapunov's first method assesses a system's stability by linearizing its dynamics around an equilibrium point, focusing on local stability. While useful for understanding stability near the equilibrium, it does

not address the system's overall stability and overlooks nonlinear phenomena. This method helps determine if a broader stability analysis is needed.

The second Lyapunov method, on the other hand, evaluates stability based on energy considerations without solving the nonlinear differential equations of the system. Stability is judged by how an energy function changes as the system evolves. To assess stability, one seeks a positive definite function $V(x)$ that represents the system's energy, with its derivative being negative semi-definite in the relevant region. Backstepping control provides a framework for designing control strategies for complex dynamic systems, ensuring their stability and convergence to desired equilibrium states [23].

5.1.1. Active power control

First, let's examine active power control. The following is the definition of the active power tracking,

$$e_1 = P_s^* - P_s \tag{4}$$

take a look at this potential Lyapunov function,

$$V(e_1) = \frac{1}{2}.e_1^2 \tag{5}$$

the Lyapunov candidate function's derivative,

$$\dot{V}(e_1) = e_1 \cdot \dot{e}_1 \tag{6}$$

$$\dot{e}_1 = \dot{P}_s^* - \dot{P}_s = \dot{P}_s^* + (1 - \frac{M_{sr}^2}{L_s.L_r}). \frac{L_r.L_s}{v_s.M_{sr}} \frac{di_{rq}}{dt} \tag{7}$$

and,

$$\dot{P}_s = (\frac{M_{sr}^2}{L_s.L_r}). \frac{L_r.L_s}{v_s.M_{sr}} \frac{di_{rq}}{dt} - 1 \tag{8}$$

The derivative of the current, i_{rq}, can be obtained by substituting the expression into the voltage equation, v_{rq} (28) and getting:

$$\dot{e}_1 = \dot{P}_s^* + \frac{v_s.M_{sr}}{(L_s.L_r - M_{sr}^2)} \left(v_{rq} - R_r.i_{rq} - (1 - \frac{M_{sr}^2}{L_s.L_r}).L_r.\omega_r.i_{rd} + g.\frac{v_s.M}{\omega_s.L_s} \right) \tag{9}$$

replacing the last in (7) gives,

$$\dot{V}(e_1) = e_1 \cdot \dot{e}_1 = e_1 \cdot = \dot{P}_s^* + \frac{v_s.M_{sr}}{(L_s.L_r - M_{sr}^2)} \left(v_{rq} - R_r.i_{rq} - (1 - \frac{M_{sr}^2}{L_s.L_r}).L_r.\omega_r.i_{rd} + g.\frac{v_s.M}{\omega_s.L_s} \right) \tag{10}$$

the following is how we arrive at the stabilizing Backstepping command expression,

$$v_{rq} = -\frac{(L_s.L_r - M_{sr}^2)}{v_s.M_{sr}}.\dot{P}_s^* + R_r.i_{rd} + \omega_r. \left(1 - \frac{M_{sr}^2}{L_s.L_r} \right).L_r.i_{rd} - g.\frac{v_s.M}{\omega_s.L_s} - (1 - \frac{M_{sr}^2}{L_s.L_r}).\frac{L_s.L_r}{v_s M_{sr}}.k_1.e_1 \tag{11}$$

to ensure convergence of the Lyapunov candidate function, replacing, expression (11) in (10) gives:

$$\dot{V}(e_1) = -k_1.e_1^2 < 0 \tag{12}$$

with k_1 positive constant.

5.1.2. Reactive power control

The discrepancy in reactive power tracking is,

$$e_2 = Q_s^* - Q_s \tag{13}$$

this equation provides the increased Lyapunov function,

$$V(e_1, e_2) = \frac{1}{2}.e_1^2 + \frac{1}{2}.e_2^2 \tag{14}$$

its derivative is given by,

$$\dot{V}(e_1, e_2) = e_1 \cdot \dot{e}_1 + e_2 \cdot \dot{e}_2 = -k_1 \cdot e_2^2 + e_2(\dot{Q}_s^* - \dot{Q}_s) \tag{15}$$

with,

$$\dot{e}_2 = \dot{Q}_s^* - \dot{Q}_s = \dot{Q}_s^* + (1 - \frac{M_{sr}^2}{L_s.L_r}).\frac{L_r.L_s}{v_s.M_{sr}}.\frac{di_{rd}}{dt} \tag{16}$$

substituting the formula for the derivative of the current ird into the voltage Vrd (27), we arrive at,

$$\dot{e}_2 = \dot{Q}_s^* + \frac{v_s.M_{sr}}{(L_s.L_r - M_{sr}^2)}\left(v_{rd} - R_r.i_{rd} + (1 - \frac{M_{sr}^2}{L_s.L_r}).L_r.\omega_r.i_{rq}\right) \tag{17}$$

by substituting the final expression in (15), we acquire,

$$\dot{V}(e_1, e_2) = -k_1.e_1^2 + e_2(\dot{Q}_s^* + \frac{v_s.M_{sr}}{(L_s.L_r - M_{sr}^2)}\left(v_{rd} - R_r.i_{rd} + (1 - \frac{M_{sr}^2}{L_s.L_r}).L_r.\omega_r.i_{rq}\right) \tag{18}$$

the expression for the stabilising Backstepping command is given by,

$$v_{rd} = -\frac{(L_s.L_r - M_{sr}^2)}{v_s.M_{sr}}.\dot{Q}_s^* + R_r.i_{rd} - \omega_r.\left(1 - \frac{M_{sr}^2}{L_s.L_r}\right).L_r.i_{rq} - (1 - \frac{M_{sr}^2}{L_s.L_r}).\frac{L_s.L_r}{v_s M_{sr}}.k_2.e_2 \tag{19}$$

if we replace (19) in (18), we obtain,

$$\dot{V}(e_1, e_2) = -k_1.e_1^2 - k_2.e_2^2 < 0 \tag{20}$$

with k_2 positive constant.

Figure 2 illustrates the power regulation block diagram for the dual-fed asynchronous machine, utilizing the Backstepping method applied to the machine-side converter.
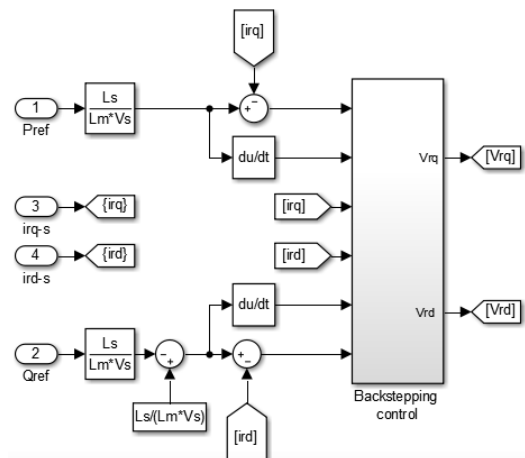

Figure 2. Diagrammatic schematic for DFIG power regulation with the Backstepping technique

5.2. Simulation results

The validation of the DFIG power control method utilizing the Backstepping technique involved rigorous numerical simulations executed via MATLAB/Simulink software. A detailed inventory of the generator parameters is available in the APPENDIXS 1 and 2. To scrutinize the control dynamics and assess its reaction to changes in stator active and reactive power, incremental steps in both active and reactive power were implemented. The ensuing machine response is visually depicted in Figures 3 and 4. Notably, Figure 3 delineates the reactive power response under the Backstepping control scheme employed for the DFIG and Figure 4 illustrates the active power response resulting from the application of Backstepping control to the DFIG.
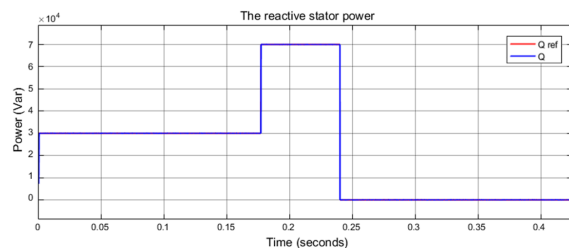
Figure 3. Power response in reaction employing Backstepping control
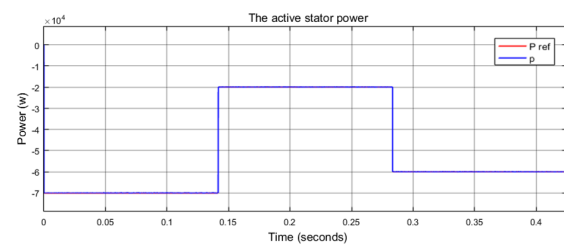
Figure 4. Active power response using Backstepping control

We proceeded to vary the active and reactive power of the system, mirroring previous tests, to assess its regulation capability. Figures 3 and 4 illustrate the simulation outcomes achieved through the Backstepping control method for the doubly-fed asynchronous generator. It's evident that the generator adeptly tracks power variations, whether in active or reactive power. The control depicted in Figures 3 and 4 underscores the satisfactory dynamics of our system. Additionally, virtually zero static error is observed for both active and reactive power. These dynamics respond promptly and exhibit no overshoot. A comparison between the performance of this control and that of an FLC control is outlined in the following paragraph.

6. ACTIVE AND REACTIVE POWER CONTROL BASED ON FUZZY CONTROLLERS

Fuzzy controllers provide a flexible approach for managing both active and reactive power, particularly when creating a mathematical model is difficult or when dealing with nonlinear system behaviors. Their growing use, especially in industrial settings, stems from their ability to handle complex and uncertain systems. Unlike binary logic, fuzzy logic deals with a spectrum of values, capturing the nuances of human reasoning and imprecise language. Introduced by Professor Zadeh, fuzzy logic employs membership functions to handle uncertainty effectively, allowing for efficient control without detailed system modeling.

FLC utilizes linguistic terms and multiple inference rules, enabling operators to apply their expertise and make decisions based on various factors. This discussion will cover the fundamental principles of FLC and the steps involved in implementing it, including the development of an FLC controller for managing the power output of a DFIG.

6.1. Basic fuzzy logic control concepts

The FLC controller operates through four primary phases: the knowledge base, fuzzification, inference engine, and defuzzification. Initially, the controller converts numerical input into fuzzy values. These values are then processed according to fuzzy rules. Finally, the fuzzy values are transformed back into physical values to generate the control signal, as the system operates with physical quantities only [23].

6.2. Fuzzification

In this phase, each variable (current and voltage) is associated with a specific fuzzy subset using quantitative membership functions to describe linguistic variables and quantify their relative uncertainty. Natural language words serve as values for these variables, which act as system inputs or outputs [23]. The inference rules result in an anti-diagonal decision table, summarized in the MACVICAR-WHELAN matrix shown in Table 1, displaying the CF inference matrix for a partition of 7 fuzzy subsets for each input variable e and Δe, for a detailed description of this part, please refer to our previous article [16].

Table 1. The basis of power control rules

Δe	e						
	NG	NM	NP	ZE	PP	PM	PG
NG	TG	TG	TG	G	PG	P	ZE
NM	TG	TG	G	G	M	P	TP
NP	TG	M	G	TG	TP	P	TP
ZE	P	PG	M	ZE	M	PG	P
PP	TP	P	TP	TG	G	MG	TG
PM	TP	P	M	G	G	TG	TG
PG	ZE	P	PG	G	GT	TG	TG

Where: ZE: zero approximately, TG: very large, P: small, M: average, TP: very positive, PG: large positive, G: large, and the corresponding linguistic values are characterised by symbols such as: NG: very negative, NM: negative average, ZE: zero approximately, NP: small negative, PM: mean positive, and PP: small positive.

6.3. Defuzzification

The core of defuzzification is decision-making, or extracting real control from control obtained as a fuzzy set. While fuzzy rule inference may be used in a variety of ways, the most often used method is the one that determines the membership function's center of gravity. This may be ascertained by applying the generic formula as (21) [24]. Figure 5 presents the schematic design of the FLC for DFIG control.

$$V_R = \frac{\int_{-1}^{1} X_k U_R(X_k) dX_k}{\int_{-1}^{1} U_R(X_k) dX_k} \tag{21}$$
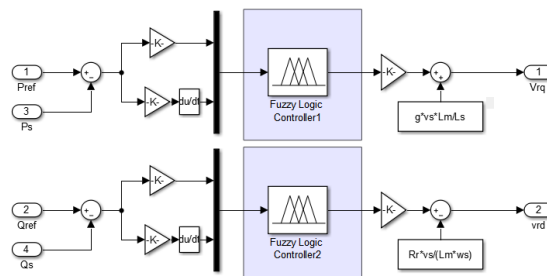
Figure 5. FLC schematic design for DFIG control

6.4. Simulation and results

We therefore subjected the system to changes in active and reactive power (similar to the previous tests) in order to study the behaviour of its regulation. Figures 6 and 7 show the simulation results obtained using DFIG fuzzy control. Figure 6 displays the active power response to FLC control of the DFIG [25], [26], and Figure 7 illustrates the reactive power response resulting from the application of FLC control to the DFIG.

The simulation results show that our system provides better tracking of the power reference, is dynamically satisfactory and the static error tends towards zero with low overshoot (no overshoot for active power). This technique made it possible to achieve perfect decoupling between the two stator power components. In order to better demonstrate the effectiveness of this control, we are going to test the behaviour of the DFIG with the variation of the parameters of the model used.

Robustness tests: parameter identification in machines is prone to inaccuracies due to the methods and measurement devices used. Consequently, the obtained values are often imprecise and subject to variations from factors such as machine heating, load changes, magnetic saturation, air gap shape, and film effects. In this section, we will examine the DFIGs response to changes in model parameters [27]. This will help us understand how parameter variations [28], influenced by operational conditions or identification errors, affect the DFIG's performance.

This analysis is crucial for evaluating the robustness of the control system against such uncertainties and parameter changes. We will test the robustness of both Backstepping and FLCs under simulated conditions to assess their effectiveness [29], [30].
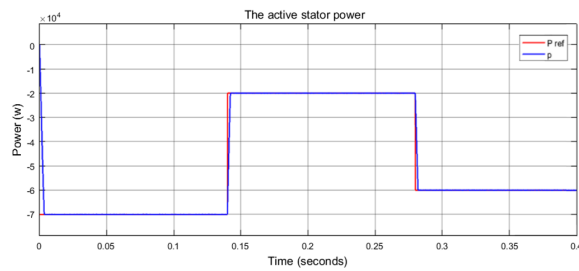
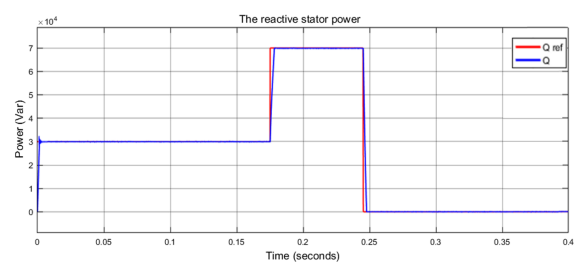Figure 6. Stator active power response using FLC control

Figure 7. Stator reactive power response using FLC control

6.4.1. Test 1: influence of a +90% variation in rotor resistance Rr

Figure 8 illustrates the impact of variations in rotor resistance on reactive power under Backstepping control of the DFIG and Figure 9 demonstrates how changes in rotor resistance affect active power when employing Backstepping control for the DFIG. Figure 10 illustrates how changes in rotor resistance impact reactive power when utilizing FLC for the DFIG, and Figure 11 illustrates how variations in rotor resistance influence active power when employing FLC for the DFIG.
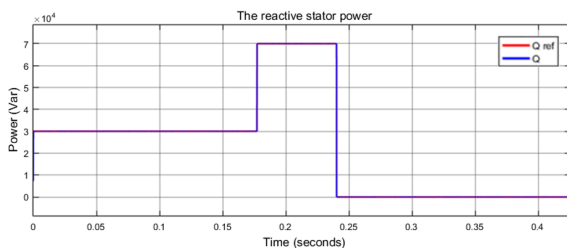
Figure 8. Backstepping control simulation results showing how changes in rotor resistance affect reactive power
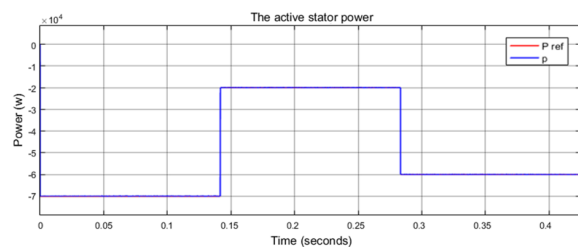
Figure 9. Results of a simulation employing Backstepping control to examine how changes in rotor resistance affect active power
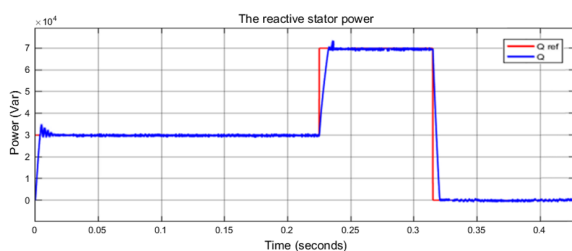
Figure 10. Results of a simulation utilizing FLC control to examine how changes in rotor resistance affect reactive power
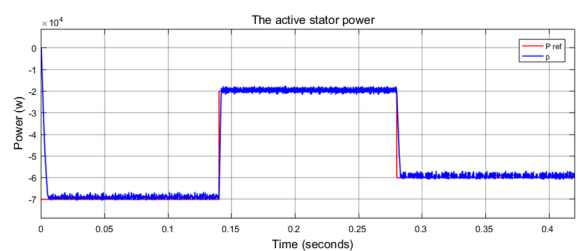
Figure 11. Results of a simulation utilizing FLC control to examine how changes in rotor resistance affect active power

6.4.2. Teste 2: influence of -35% variation in mutual inductance Lm

Figure 12 demonstrates the influence of variations in rotor mutual inductance on reactive power under Backstepping control for the DFIG and Figure 13 illustrates the influence of variations in rotor mutual inductance on active power when employing Backstepping control for the DFIG. Figure 14 illustrates how variations in rotor mutual inductance influence active power when employing FLC for the DFIG, and Figure 15 illustrates how variations in rotor mutual inductance impact active power when utilizing FLC for the DFIG.
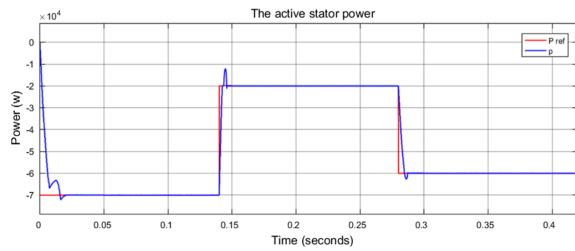
Figure 12. Results of a simulation utilizing Backstepping control to examine how changes in rotor mutual inductance affect reactive power
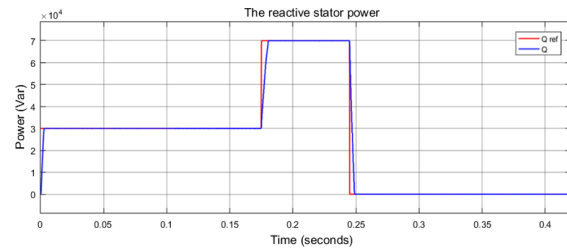

Figure 13. Results of a simulation employing Backstepping control to examine how changes in rotor mutual inductance affect active power
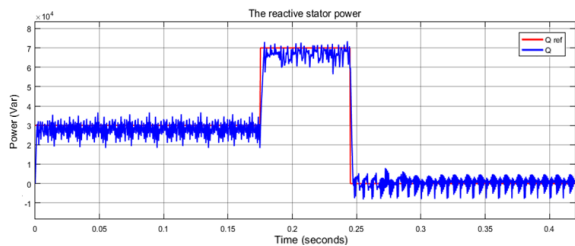

Figure 14. Results of an active power simulation employing FLC control to examine the impact of rotor mutual inductance fluctuations
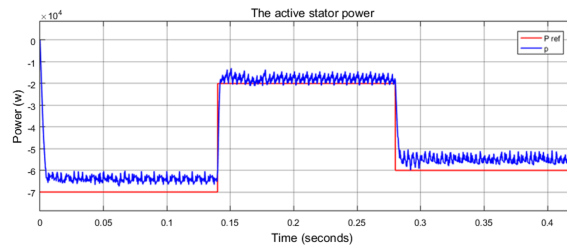

Figure 15. Results of a reactive power simulation employing FLC control for the impact of changes in rotor mutual inductance

7.   RESULTS AND DISCUSSION

The outcomes of this study indicate that altering parameters in the DFIG model notably impacts the active and reactive power profiles regulated by FLC, as depicted in Figures 14 and 15. Specifically, increasing the rotor resistance (Rr) by 90% resulted in distinct variations in the FLC control outputs, overshoot (active power, Figure 11), and response times for both active and reactive powers (Figures 10 and 11). Additionally, abrupt oscillations were observed despite an increase in the static error of active and reactive powers by 35% of the nominal value of the mutual inductance (Lm), as illustrated in Figures 14 and 15. This finding suggests that the FLC method is not resistant to internal parametric fluctuations, validating the reliance of the FLC control law on the rotor resistance and mutual inductance of the DFIG. Our results in Figures 8, 9, 12, and 13 show that the Backstepping control also affects the reactive and active power curves under DFIG model parameter changes. However, the robustness and dependability of Backstepping control are demonstrated by its ability to maintain stator active and reactive power tracks relative to their references, even when the rotor resistance Rr rises by 90%. Notably, when the mutual inductance Lm is varied by 35% of its nominal value, there is an increase in reactive power overshoot (Figure 12) and power response time (Figures 12 and 13), with no change in the static error. From these robustness tests, it is evident that variations in resistances and mutual inductances have minimal influence on the performance of Backstepping-based control.

This study investigated the application of the Backstepping control law to the power generation system of a doubly-fed asynchronous generator (DFIG). While earlier studies have explored various control methods for DFIGs, they have not explicitly addressed the comparative influence of Backstepping and fuzzy logic on performance metrics under varying operating conditions. We found that Backstepping control provided superior reference tracking and reduced overshoot compared to FLC under various conditions.

The proposed method in this study tended to have a significantly higher proportion of effective active and reactive power regulation, showing improved dynamic response. Our study suggests that higher robustness against parameter variations in DFIGs is not associated with poor performance in power regulation. The proposed Backstepping method may benefit from systematic design without adversely impacting the adaptability of FLC. However, the FLC's flexibility in handling non-linear systems like wind turbines offers strong performance, despite parameter fluctuations. This study explored a comprehensive control strategy with Backstepping and FLC. However, further and in-depth studies may be needed to confirm their efficacy, especially

regarding their long-term performance under different operational scenarios. Our findings imply that both control methods are effective for enhancing DFIG wind turbine reliability and power quality.

Future research could optimize these controllers further, explore hybrid approaches, and test their adaptability in more complex scenarios, including energy storage integration for broader renewable energy applications. Recent observations suggest that advanced control methods like Backstepping and fuzzy logic significantly improve the stability and performance of DFIG-based wind turbine systems. Our findings provide conclusive evidence that these methods are associated with enhanced power regulation and robustness, not merely due to elevated adaptability to parameter variations, can be seen in Table 2.

Table 2. Comparison between fuzzy logic and Backstepping control

Control type	Response time (seconds)	Static error
Fuzzy logic control	0.0024s	0.9741
Backstepping control	0.00031s	0.996

8. CONCLUSION

The numerical simulations clearly show the advantages of Backstepping and FLCs for DFIG-based wind turbine systems. Both methods effectively regulated active and reactive power with good dynamic responses. Backstepping control provided superior reference tracking and reduced overshoot compared to fuzzy logic under various conditions. Fuzzy logic, with its simple, data-driven approach, offered strong performance and robustness for complex nonlinear systems like wind turbines. The comparative analysis revealed that Backstepping control excelled in performance metrics such as overshoot and tracking speed, thanks to its systematic design. In contrast, FLC proved robust against parameter variations due to its flexible rule-based approach. Both techniques are effective for enhancing DFIG wind turbine reliability and power quality. Future research could optimize these controllers further and explore hybrid approaches, as well as test their adaptability in more complex scenarios, including energy storage integration for broader renewable energy applications.

APPENDIX 1: DFIG PARAMETERS

Rated power: 80 kW.

Rotor resistance = 0.019 Ω.

Stator resistance Rs = 0.018 Ω .

Mutual inductance M = 8.17 mH.

Stator inductance Ls = 8.49 mH .

Rotor inductance Lr = 2.587 mH.

Number of pole pairs p = 3.

Moment of inertia J=1000 Kg.m^2.

Coefficient of friction f = 0.0024 N.m.s/r.

APPENDIX 2: WIND TURBINE PARAMETERS

Rated power: Pn=80 kW.

Radius of the blade R=8.3 m .

Number of blades 3 .

Gear ratio G=80.

Viscous friction coefficient fr =0.0024 N.m^-1

Nominal wind speed v= 12 m/s.

Moment of inertia J=1300 Kg.m^2.

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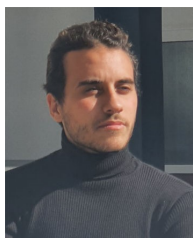
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