

Performance Improvement of Wind Energy Conversion Systems Based on DFIG: A Comparative Study Between Linear & Nonlinear Control

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Abstract - In this study, we present a comprehensive comparative analysis of Proportional-Integral (PI) control and Backstepping control (BCS-Control) strategies applied to a Doubly Fed Induction Generator (DFIG) for variable-speed wind energy conversion systems (WECS). The objective is to decouple the active and reactive power generated by a DFIG, which is widely employed in modern wind turbines due to its enhanced efficiency and controllability. Simulation results on a 1.5 MW DFIG system are provided to demonstrate the effectiveness and robustness of the proposed control strategy during variations in active and reactive power, rotor speed, and machine parameters.

Keywords – Wind turbine, DFIG, PI-Control, Backstepping Control.

I. INTRODUCTION

Renewable energy sources are in increasing demand due to their environmentally friendly energy production and their potential to mitigate issues related to conventional energy sources such as environmental pollution and global warming [1]. Over the years, numerous technologies have been proposed. In this research, we specifically focus on grid-connected, variable-speed wind turbines equipped with a DFIG. The DFIG features a wound rotor induction generator configuration, where the stator windings are directly connected to the electrical grid. In contrast, the rotor windings are linked through two converters: the Rotor-Side Converter RSC and the Grid-Side Converter GSC. These converters are separated by a DC-link capacitor, which serves as an energy storage component [2-4].

PI controllers are extensively employed in linear control applications to attain desired system responses by modifying the control output

in response to the error. Their purpose is to offer both rapid responses to system changes and a mechanism for eradicating long-term errors, thus guaranteeing system stability and precise attainment of the desired setpoint. Nevertheless, these methods encounter several limitations, particularly concerning variations in machine parameters [3]. Research [5-7] has indicated that substituting the PI controller with a nonlinear control approach can address these issues more effectively.

The choice of a nonlinear control method depends on the specific characteristics of the system and the control objectives. One such approach, the Backstepping technique, has been developed by Kokotovic [8] and is relatively recent in the field of controlling nonlinear systems [5,9]. This method is particularly notable for its ability to decompose complex nonlinear control problems into simpler, smaller problems [6-10]. The fundamental concept behind Backstepping involves computing a control law in multiple stages to establish a Lyapunov

affirmed the stability of both methods without any signs of oscillations or instability. Moreover, BCS-Control displayed superior tracking precision, closely adhering to the reference signal. While PI control required slightly less control effort. Furthermore, the rotor current direct and quadrature curves indicated that they vary in tandem with changes in reactive and active power respectively. When the power factor is equal to one ($F_p=1$), the reactive power is equal to zero ($Q_s = 0$).

B) Robustness test

The objective of robustness testing is to determine the system's or process's ability to maintain functionality, accuracy, or stability even when faced with unexpected variations, disturbances, or uncertainties.

In this test, we are altering the criteria of the DFIG model used by reducing the stator inductance L_s and rotor inductance L_r by 10% of their nominal values, in order to study the performance of DFIG. Figure 10 represents the simulation results of the BCS-Control applied to the WECS with varying parameters of DFIG. The simulation results of the PI-Control have not been presented because it is a non-linear control that does not yield the desired results, as indicated in reference [2].

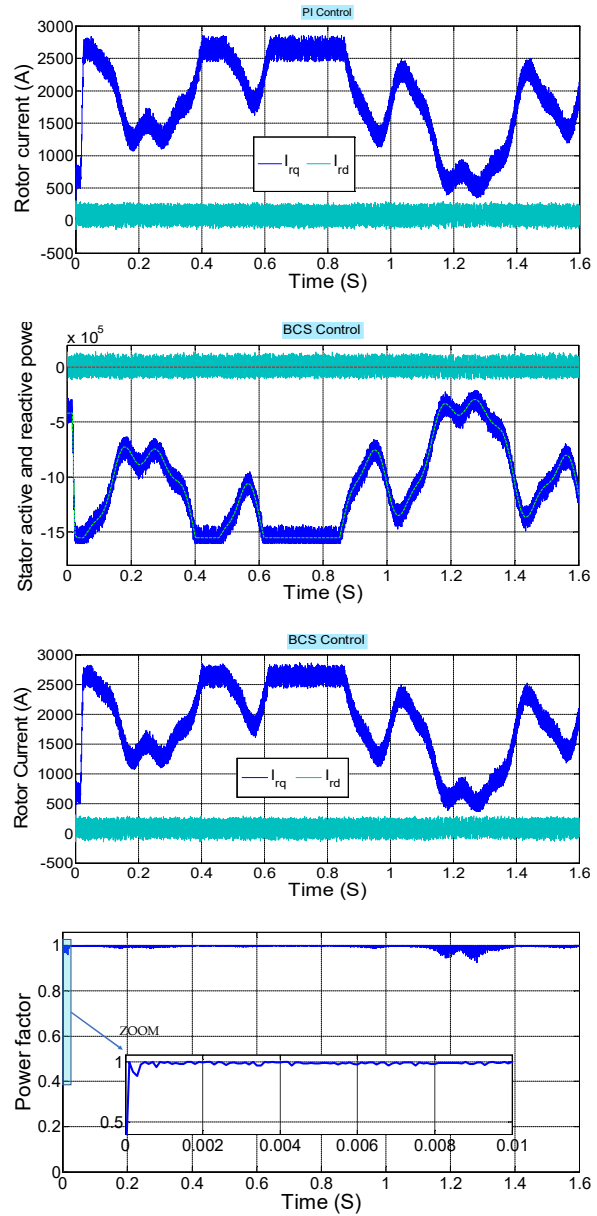
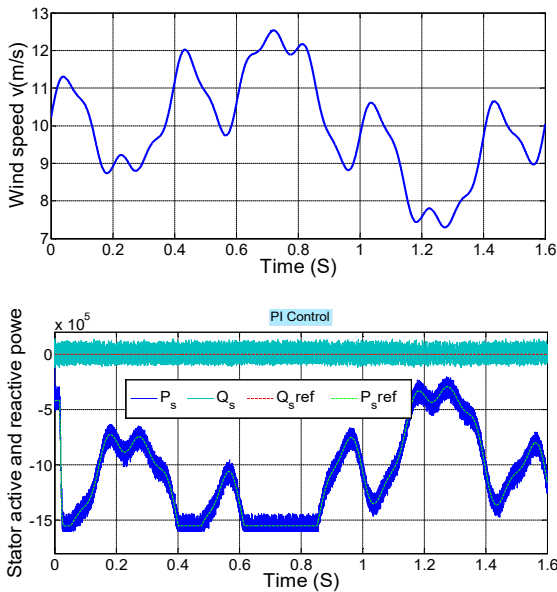
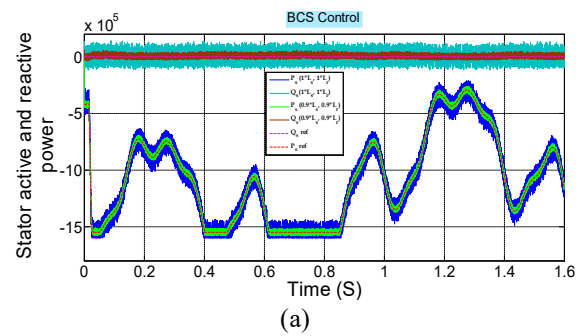


Fig. 3. Simulation results of the both PI-Control and BCS-control applied to the DFIG.



(a)

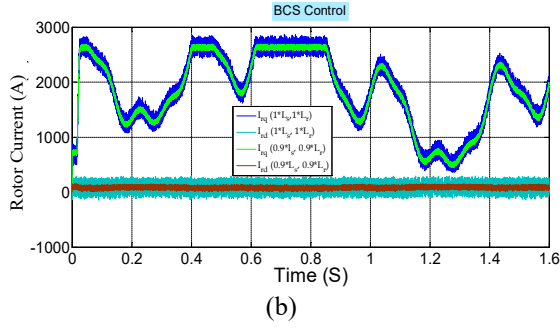


Fig. 4. Simulation results for BCS-Control with variations in the parameter of DFIG: (a) Stator active and reactive power (b) Rotor current.

Through the simulation results described in Figure 4, the both linear and non-linear controls, exhibit good dynamic and static performance, despite variations in the DFIG parameters, this analysis suggests that BCS-Control outperforms PI-Control in terms of transient response and tracking accuracy, making it a promising choice for this application.

The comparison between PI-Control and BCS-Control can be summarized in table 3:

Table 3. Comparison Between PI-Control And BCS-Control

Control Strategy	PI-Control	BCS-Control
Approach	Linear	Nonlinear
Complexity	Low	Moderate to High
Adaptability	Limited	High
Tracking Accuracy	+++	++++
Static error (%)	7.89	6.65
Overrun (%)	0	0
Disturbance Rejection	Fair	Excellent
Stability	Limited	Improved
Wind Variability	Fair	Very Good
Response Time (ms)	$3 \pm 5\%$	$1.8 \pm 5\%$
Robustness	No	+++++

VII. CONCLUSION

This paper presents a comparative study between linear and nonlinear control strategies for DFIG-based wind energy conversion systems. The simulation results obtained using environment MATLAB Simulink emphasize the importance of selecting an appropriate control strategy based on specific wind conditions and system requirements. The results indicate that the BCS-Control unit provides significant robustness compared to the vector control, despite variations in the parameters of DFIG. Future research could delve deeper into hybrid control strategies that

combine the advantages of both linear and nonlinear methods to further enhance the overall performance of variable-speed DFIG systems in wind turbines.

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IX. APPENDIX

Table 1. Wind Turbine Parameters

R =35.25 m	Blade radius
np =3	Number of blades
G =90	Gearbox ratio
J = 10^3 Kg.m ²	Inertia
$f_r = 2.4 * 10^{-3}$ N.m.S ⁻¹	Viscous friction coefficient
V =12 m/s	Nominal wind speed

Table 2. DFIG Parameters

P _n =1.5 MW	Rated power
V _r =225V	Rotor rated voltage
V _s = 398 V	Stator rated voltage
I _n =1900A	Rated current
f =50Hz	Stator rated frequency
L _m =13.5 mH	Mutual inductance
L _s = 13.7 mH	Stator inductance
L _r = 13.6 mH	Rotor inductance
R _s = 12 mΩ	Stator resistance
R _r = 21 mΩ	Rotor resistance
P = 2	Number of Pole pairs

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