

# Comparative Study of the Control Performance in DC Grid Tied DFIG based Marine Current Turbine Generator System

Yosra Smai<sup>1,2</sup>, Bilel Touati<sup>2,3</sup>, Hechmi Ben Azza<sup>1,2</sup> and Abdoul Rjoub<sup>4</sup>

<sup>1</sup> Université de Tunis, Ecole Nationale Supérieure d'Ingénieurs de Tunis (ENSIT), 5 Avenue Taha Hussein, PO Box 56, 1008, Tunis, Tunisie.

<sup>2</sup> Laboratoire de l'Ingénierie des Systèmes Industriels et des Energies Renouvelables (LISIER).

<sup>3</sup> Institut Supérieur des Sciences Appliquées et Technologies de Kasserine, Université de Kairouan, Tunisie.

<sup>4</sup> Computer Engineering Department, Jordan University of Science and Technology, Jordan

\*Cor. Author: touaitibilel@gmail.com

**Abstract**—This paper presents a simulation and experimental analysis of a Marine Current Turbine (MCT) system based on a Doubly Fed Induction Generator (DFIG) connected to a DC bus. We propose a Field-Oriented Control (FOC) strategy to regulate the DFIG-DC system, utilizing both Proportional-Integral (PI) controllers and High-Order Sliding Mode (HOSM) controllers. A comparative study evaluates the performance of these regulators, emphasizing their differences in efficiency, robustness, and dynamic response. The results offer insights into the advantages and limitations of each control approach, contributing to the optimization of DFIG-based power conversion systems.

## I. INTRODUCTION

The ocean, covering approximately 70% of the Earth's surface, presents a significant opportunity for renewable energy generation. Among these sources, marine current turbines stand out due to their high predictability and energy density, making them highly promising for commercial exploitation [1-2]. The concept behind these turbines is similar to that of wind turbines, both harnessing kinetic energy and converting it into mechanical energy through a rotating mechanism. However, marine current turbines offer a substantial advantage due to the higher density of water compared to air [3]. These turbines can be categorized into two main types: vertical axis and horizontal axis [4]. Each type has its own unique design and operational characteristics, with the choice often depending on factors such as the specific site conditions and the desired energy output.

During the last years, the alternative current was the first method for transmitting electrical energy. Recently, the High-Voltage Direct-Current (HVDC) is an important solution for a special application such as tidal turbines parc located over 100Km thanks to its advantages such as power transmission over long distances, especially for tidal turbine parks, which provide precise control of the power flux, reduced sensitivity to disturbances such as frequency variations and voltage dips and smaller cable sizes.

Doubly Fed Induction Generator (DFIG) is used in wind conversion systems and Marine Current Turbines (MCT) thanks to the controllable abilities, the robustness and the low-cost installation [5]. Typically, DFIG is used in AC generation systems where the stator windings are connected directly to the electrical grid. The rotor windings are connected to this grid through two back-to-back converters [6]. In the DFIG-DC system topology, a single controllable converter is used to control the rotor currents while the stator windings are connected to the DC bus through a diode rectifier [7].

This study presents a Field Oriented Control (FOC) strategy for rotor side converter. By using traditional controllers to regulate the rotor currents, the DC voltage and stator frequency are kept within their reference values despite changes in the load and tidal speed [8-9]. In terms of robustness and performance results, classic control laws will be insufficient. The chattering phenomena can be limited by the use of the Super-Twisting algorithm for High-order Sliding Mode (HOSM) control [10–11]. In addition, it provides better performances than classic regulators, and it attenuates harmonics without the necessity of using a filter. The objective of this research is to evaluate and compare the robustness and performance of classical Proportional-Integral (PI) controllers with HOSM controllers in controlling a DFIG-based MCT system. Specifically, the study focuses on regulating the rotor currents in the d-q reference frame and stabilizing the DC-link voltage. To assess the effectiveness of both approaches, simulations are conducted under various operating conditions, including tidal speed variations.

This paper present four Section, section II presents the DFIG modelling and MCT speed, section III describes the rotor current controllers, section IV present the simulation and the experimental results. Finally, the conclusion is presented in section V.

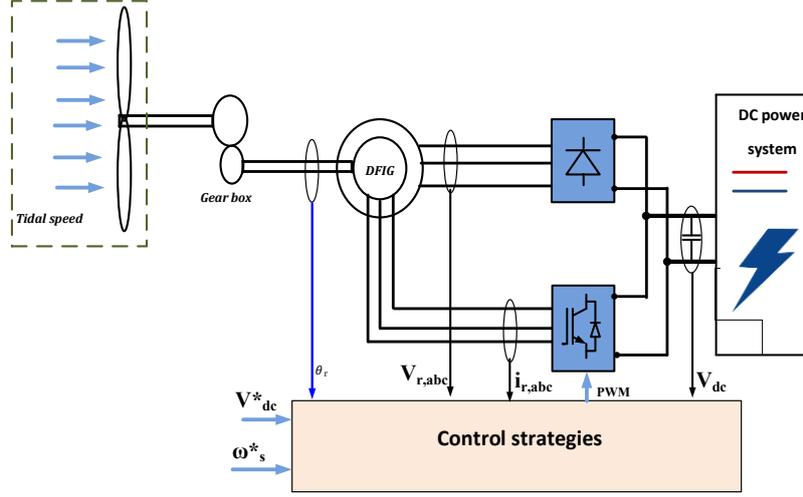


Figure 1. DFIG-DC system configuration.

## II. DFIG MODELLING

The DFIG-DC system topology consists of a DFIG where the stator is directly connected to the DC bus through an uncontrolled diode rectifier, while the rotor is interfaced with the DC bus via a fully controlled power converter (Fig. 1). In this configuration, the stator's AC output is rectified passively, ensuring a simple and robust connection to the DC link. Meanwhile, the rotor-side converter actively regulates power flow, enabling independent control of torque and reactive power. This topology enhances system stability, eliminates synchronization issues, and facilitates direct integration with DC grids or energy storage systems., The DFIG has three stator windings and three rotor windings as shown in Fig.2.

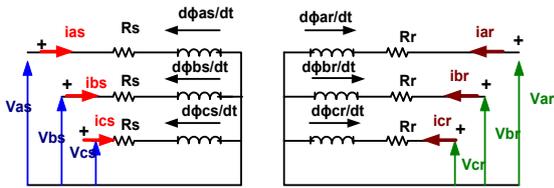


Figure 2. Equivalent scheme DFIG-configuration.

The model of the DFIG is defined in the fundamental d and q-axis frame as:

$$\begin{cases} V_{s(d,q)} = \frac{d\phi_{s(d,q)}}{dt} + R_s I_{s(d,q)} \mp \omega_s \phi_{s(d,q)} \\ V_{r(d,q)} = \frac{d\phi_{r(d,q)}}{dt} + R_r I_{r(d,q)} \mp \omega_r \phi_{r(d,q)} \end{cases} \quad (1)$$

And

$$\begin{cases} \phi_{s(d,q)} = L_s I_{s(d,q)} + M I_{r(d,q)} \\ \phi_{r(d,q)} = L_r I_{r(d,q)} + M I_{s(d,q)} \end{cases} \quad (2)$$

The rotor and stator powers equations are given by:

$$\begin{cases} P_s = V_{sd} I_{sd} + V_{sq} I_{sq} \\ Q_s = V_{sq} I_{sd} - V_{sd} I_{sq} \\ P_r = V_{rd} I_{rd} + V_{rq} I_{rq} \\ Q_r = V_{rq} I_{rd} - V_{rd} I_{rq} \end{cases} \quad (3)$$

In this study, Stator Field Orientation Control (SFOC) will be used in order to have a decoupling of the rotor quantities:

$$\begin{cases} \phi_{sd} = \phi_s = M I_m \\ \phi_{sq} = 0 \end{cases} \quad (4)$$

So, the stator active and reactive power can be written according to the rotor currents. This leads to a decoupled power control as shown in the following equation:

$$\begin{cases} P_s = -\frac{V_s M}{L_s} I_{rq1} \\ Q_s = \frac{V_s}{L_s} \phi_s - \frac{V_s M}{L_s} I_{rd1} \end{cases} \quad (5)$$

## III. Rotor Current Controllers Analysis

### A. PI Controllers Analysis

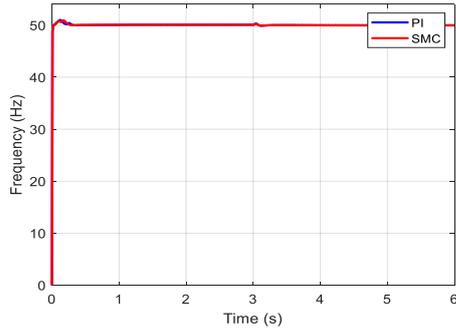
The control strategy of the rotor side converter contains two regulation loops, one inner loop for currents regulation and one outer loop for DC voltage regulation. In order to keep the DC bus voltage constant, this voltage is regulated through an external loop by means of PI controller whose role is to generate the d-axis rotor current reference.

The d and q-axis rotor currents can be represented by the transfer functions given by the following equations:

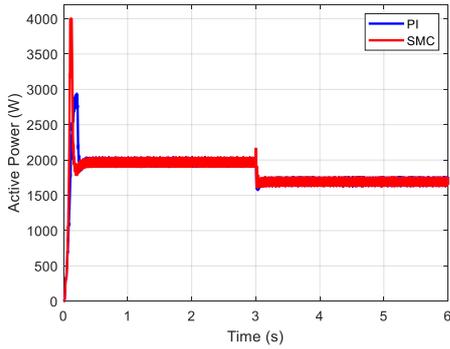
$$I_{rd} = \frac{\frac{1}{R_r}}{1 + \frac{L_r \sigma}{R_r} s} (V_{rd} - E_d) \quad (6)$$



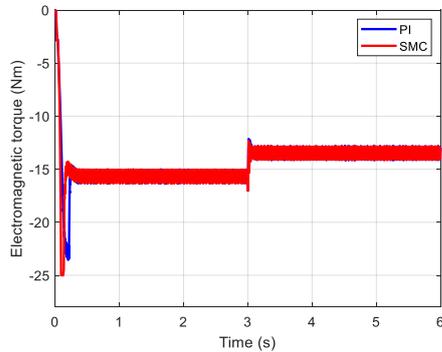




(a)



(b)



(c)

Figure 6: Simulation results of the MCT based on DFIG-DC system using a PI and HOSMC.

The experimental results clearly illustrate the superior performance of the HOSM controller when compared to the classical PI controller. As shown in Fig. 8(a), the DC voltage regulated by the HOSMC quickly converges to its reference value with minimal steady-state error and significantly reduced settling time. In contrast, the DC voltage response under the PI controller (Fig. 8(b)) exhibits a slower transient response, taking longer to reach steady state. Additionally, analysis of the rotor current waveforms indicates that the HOSMC maintains a nearly ideal sinusoidal shape without overshoot or oscillations (Fig. 9(a)), demonstrating excellent harmonic

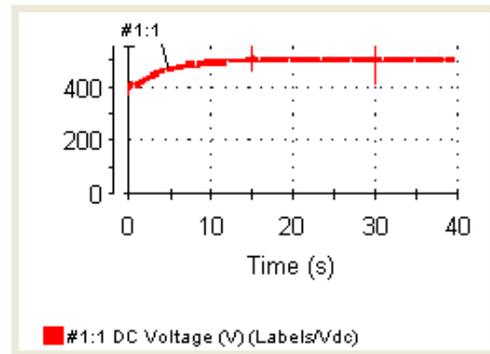
attenuation and precise current regulation. Conversely, the rotor currents under PI control (Fig. 9(b)) show noticeable deviations from the sinusoidal reference, including minor overshoot and harmonic distortion, which can lead to increased losses and mechanical stress.



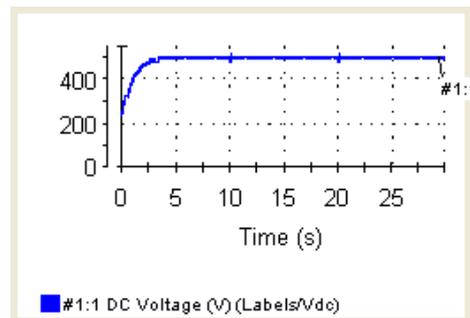
Figure 7 : Photograph of the experimental test bench

TABLE I. Parameters of the 0,8 kW DFIG used in the experimental tests

$R_s$	8.1	Rated power	2.5 kW
$\Omega$		Rated voltage	500
$R_r$	9.9 $\Omega$	V	
$L_{fs}$	0.0537 H	Stator rated current	2 A
$L_{fr}$	0.0537 H	Rotor rated current	4 A
M	0.6311 H	Rated frequency	50 Hz
J	0.001878	Number of pole pairs	2
$\text{Kg.m}^2$			

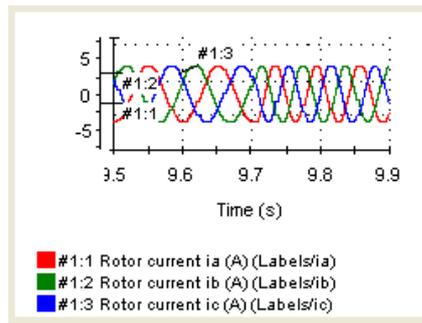


(a)

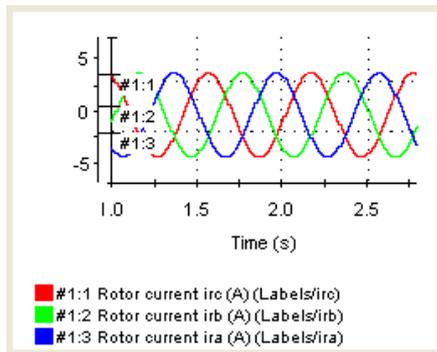


(b)

Figure 8 : Experimental results of DC voltage



(a)



(b)

Figure 9: Experimental results for a MCT driven DFIG-DC system

## V. CONCLUSION

This study presents a comparative evaluation of classical PI controller and HOSM controller for controlling rotor currents and regulating DC-link voltage in a MCT system using a FOC strategy. The simulation and experimental results indicate that HOSMC demonstrates greater robustness, faster dynamic response, and improved harmonic current suppression compared to the traditional PI approach. Furthermore, a resonant control strategy was effectively implemented to reduce torque ripple, significantly enhancing the mechanical smoothness and operational stability of the turbine. The distinctive contribution of this research is the application of nonlinear robust control techniques—specifically HOSMC—in the context of MCTs, where fluctuations in marine current speed and challenging operating conditions pose significant control obstacles. Theoretically, this work advances the application of advanced control methods in ocean energy systems, while practically providing valuable insights for enhancing the efficiency, reliability, and lifespan of MCT systems.

Acknowledgments

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