Advanced control of active and reactive power of DFIG in wind energy conversion system using fuzzy logic type **The First National Conference on Renewable Energies and Advanced**

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Fractional Order Modeling for Improved Stability of DC Microgrids under Dynamic Conditions

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Abstract

The increasing complexity of DC microgrids (MGs), especially with the integration of renewable sources and variable loads, has heightened the need for more accurate system modeling and robust control strategies. Traditional integer-order (IO) models of power converters often fail to capture the true dynamic behavior of physical components, such as capacitors and inductors, which can lead to inaccurate predictions and poor stability margins. In this work, a fractional order (FO) approach is employed to model a DC/DC buck converter within a microgrid. The Oustaloup Recursive Approximation (ORA) method is utilized to represent the FO dynamics of the system components, enabling better alignment with real-world behaviors. A nonlinear FO backstepping controller is then designed to regulate the output voltage and maintain DC bus stability. The fractional Lyapunov function is used to mathematically verify the closed-loop system's asymptotic stability. Numerical simulations under various disturbances demonstrate that the FO controller offers superior transient response and stability compared to its integer-order counterpart. The results highlight the potential of fractional calculus to enhance voltage regulation, robustness, and reliability in future-generation DC microgrids, especially under uncertain and dynamic conditions.

Introduction

DC microgrids are increasingly recognized as an efficient solution for integrating distributed energy resources, offering improved energy management and reliability. However, ensuring voltage stability under varying load and operating conditions remains a key technical challenge. This poster explores the use of fractional calculus for the modeling and control of DC/DC converters in microgrids [1]. Fractional-order systems provide more flexible and accurate dynamic models, allowing for enhanced control performance. The results demonstrate that incorporating fractional-order control significantly improves the voltage regulation and overall stability of DC microgrids under dynamic and uncertain conditions.

Fractional-Order Buck Converter Modeling

According to the linear models proposed by Westerlund as well as the fact that the converter is assumed to be operating in CCM [2], the dynamic equations of the FO buck converter feeding a constant power load [3] and a resistive load is expressed bellow

$$\begin{cases} \dfrac{d^m v_C}{dt^m} = \dfrac{i_L}{C} - \dfrac{i_R}{C} - \dfrac{i_P}{C} \\ \dfrac{d^p i_L}{dt^p} = \dfrac{v_{in}}{L} d - \dfrac{v_C}{L} \end{cases}$$

Construction of the Proposed Nonlinear Control Scheme

- The control input of DC-DC buck converter is

$$d = \frac{1}{v_{in}} \begin{bmatrix} e_1 + \dot{\tilde{v}}_C + L D^p \beta - \frac{L}{C} e_2 \, sign(D^{m-\alpha} e_1) \\ sign(D^{p-\alpha} e_2) - L K_2 D^{p-\alpha} e_2 \end{bmatrix}$$

For $K_1 > 0$ and $K_2 > 0$, the system above is globally asymptotically stable, In which the tracking error dynamics e_1 and e_2 are chosen as

$e_1 = v_C - \tilde{v}_C$.

$e_2 = i_L - \beta$.

In addition, the virtual controller is as

$\beta = -C K_1 D^{m-\alpha} e_1 + C D^m \tilde{v}_C + i_R + i_P$.

Now, define the Lyapunov function as

$$V_1 = |D^{q_1-\alpha} e_1|$$

This candidate uses the absolute value to handle the incommensurate fractional orders, offering a simplified and unified approach to ensure positivity and facilitate stability analysis.

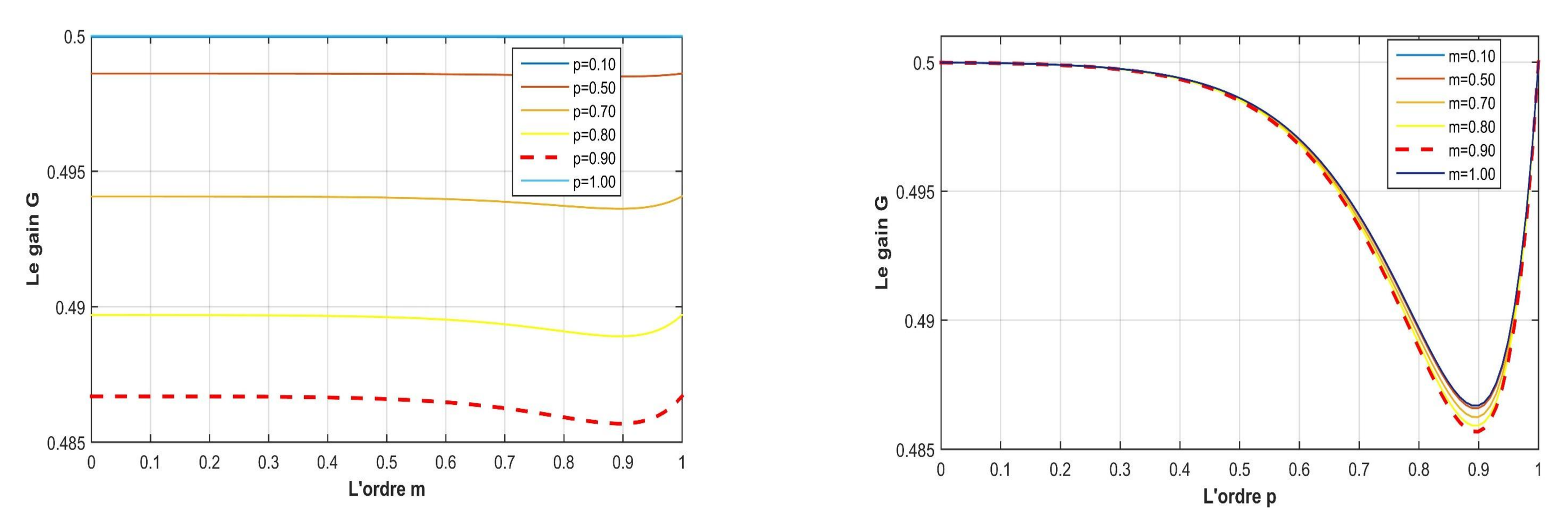

Fig. 1: The relationship between the voltage gain and the orders (m, p) in a buck converter.

Results

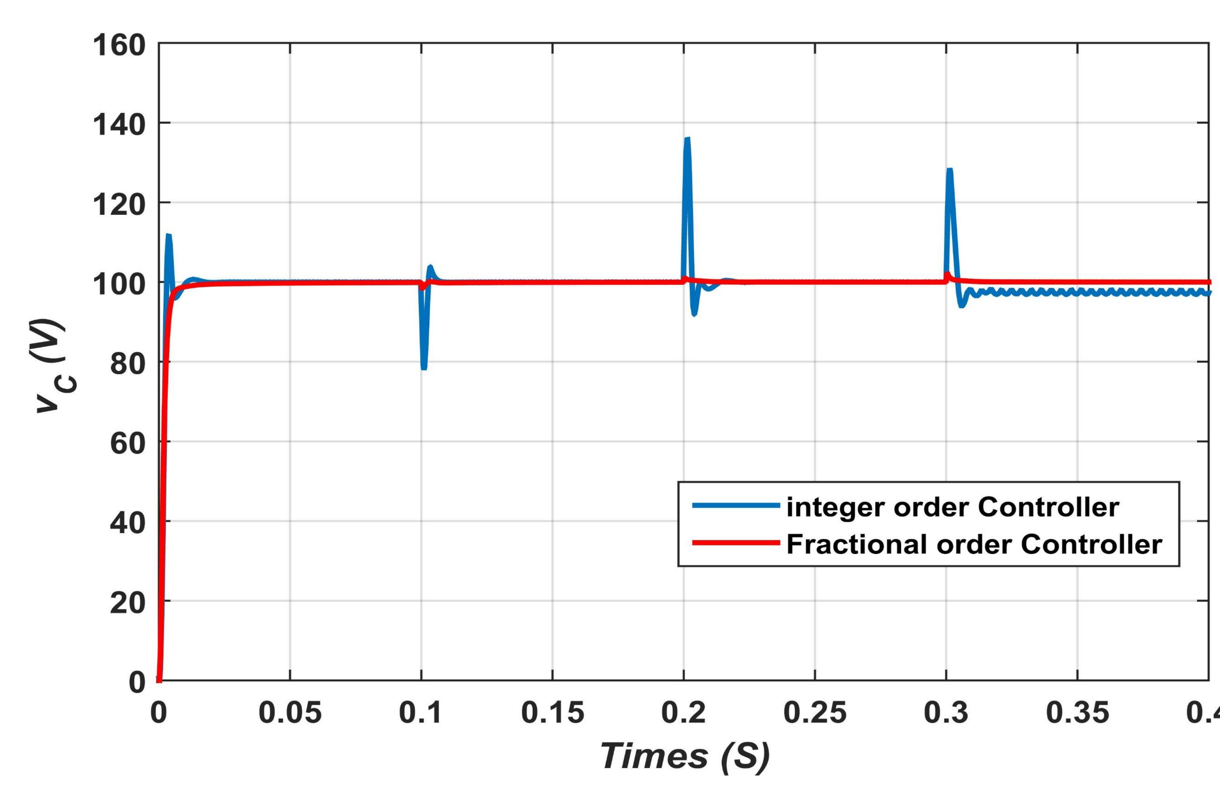

Fig. 2: Simulation Results with a Changing Resistive Load.

"Figure 2 shows the effect of resistive load variation on the FO buck converter response. The load changes from 10 Ω to 5 Ω at 0.1 ms and 5 Ω to 12 Ω at 0.2 ms. At 0.2 ms, the IO converter exhibits a high overshoot of 36.2 V, while the FO converter shows only 2.5 V with faster settling. At 0.3 ms, a CPL is applied. The IO controller fails to maintain performance, causing a 2.89 V drop and oscillations. In contrast, the FO converter remains stable with negligible error. This highlights the improved robustness and stability of the FO buck converter using a FO BSC controller."

Conclusion

By applying fractional calculus in both modeling and control, this study demonstrates enhanced stability in DC microgrids. The proposed fractional-order backstepping controller effectively regulates the output voltage, even under dynamic conditions and external disturbances. Notably, the controller's performance was evaluated under varying constant power load conditions, which are known to induce instability. The results confirm that the fractional-order approach significantly improves system robustness and damping characteristics. These findings highlight the suitability of FO-based control strategies for developing future resilient and stable microgrid architectures.

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