Fuzzy logic-based adaptive virtual inertia control for enhancing frequency stability in low-inertia microgrids

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ABSTRACT

The increasing integration of renewable energy sources (RES) is accelerating the shift from traditional synchronous machine-based power systems to inverter-dominated grids. This transition poses significant frequency stability challenges, as power electronic interfaces lack the inherent kinetic energy storage of conventional generators, resulting in low system inertia. To address these challenges, this study proposes an adaptive virtual inertia control system based on fuzzy logic, which offers notable advancements in frequency dynamics. The proposed controller dynamically adjusts the virtual inertia constant in real-time by leveraging inputs such as frequency and the rate of change of frequency (RoCoF). This adaptive approach overcomes the limitations of fixed inertia systems, ensuring improved frequency stability and superior transient performance during load disturbances. Simulation results validate the system's effectiveness, showing reduced frequency overshoots, minimized deviations, and faster recovery to nominal frequency compared to conventional fixed inertia methods. By rapidly damping oscillations and enhancing transient stability, the proposed system significantly outperforms traditional techniques. Moreover, the study reviews current virtual inertia strategies, control topologies, and explores future research directions for integrating advanced virtual inertia into modern grids. These findings demonstrate the robustness of fuzzy logic-based adaptive inertia for stabilizing low-inertia microgrids with high RES penetration.

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1. INTRODUCTION

Due to the growing integration of renewable energy sources (RES), especially solar and wind, the global energy landscape is experiencing a substantial transition [1]. This shift is not only environmentally motivated but also economically driven, as the cost per kWh of renewable energy production continues to decline, making renewables more competitive. Additionally, optimizing renewable energy production through efficient energy management further enhances its viability [2], this transition, while crucial for mitigating climate change, presents substantial challenges for maintaining grid stability [2]. The international energy agency (IEA) predicts a huge growth of renewable energy sources over the coming decades, driven by the need to curb climate change and greenhouse gas emissions in the power sector [3]. This transition, however, presents substantial challenges for maintaining grid stability, particularly frequency stability, as increasing RES penetration with variable power output can lead to power imbalances and frequency deviations. A major concern in this context is the reduced global system inertia due to the displacement of conventional generators with synchronous machines [4] (see Figure 1). Furthermore, the unpredictable characteristics of both RES generation and load demand add complexity to the problem of maintaining frequency stability [5].

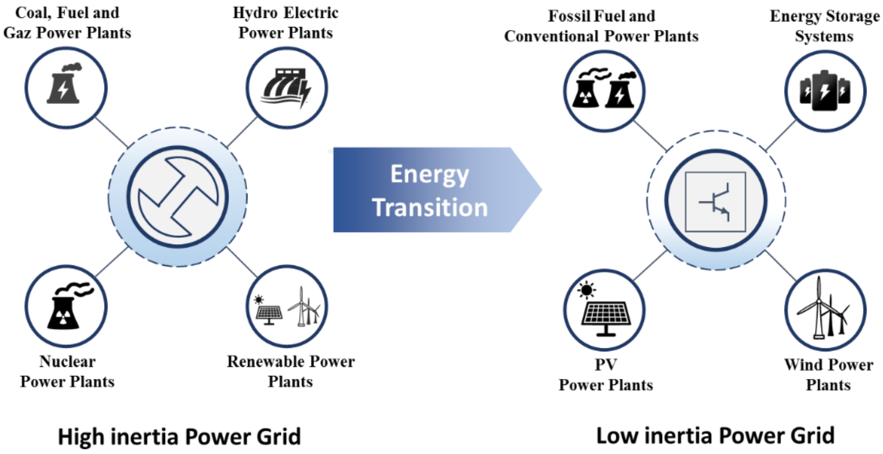

Figure 1. Global energy transition [6]

The increasing integration of renewable energy sources, particularly those replacing conventional synchronous generators with their rotating masses, raises major concerns regarding system inertia [6], [7]. Unlike synchronous machines, power electronic interfaces contribute minimal inertia to the grid, increasing susceptibility to frequency deviations and high rates of change of frequency (ROCOF) during power imbalances [8]. Low-inertia systems are particularly vulnerable, experiencing high frequency dynamics during disturbances and increased risk of cascading failures leading to blackouts compared to high-inertia systems [9], [10]. Addressing these challenges is critical to ensuring grid stability, and virtual inertia (VI) has emerged as a promising solution.

Researchers have proposed various VI control strategies that emulate the inertial response of synchronous machines through advanced inverter-based techniques. These approaches, collectively known as virtual inertia, provide a controllable source of inertia-like response to frequency deviations, enhancing system stability and frequency regulation in low-inertia grids with high renewable energy penetration [11]. VI approaches aim to emulate the behavior of synchronous machines using inverter-based control strategies. A variety of VI control techniques have been explored, ranging from classic methods like proportional-integral (PI) and proportional-resonant (PR) control to advanced approaches leveraging model prediction and machine learning [12]. Specific VI techniques include virtual synchronous machines (VSMs) [13], [14], virtual induction machines (VIMs), and inertia emulation in renewable energy sources like wind turbines and solar PV panels [15]. Additionally, specific control strategies like, synchronverter, IseLab, and virtual oscillator control have been investigated [13]. Control strategies like the coefficient diagram method, H-infinity control [16], and adaptive learning have been proposed to improve transient stability [17].

In this paper, we investigate the role of virtual inertia in improving the stability of low-inertia power systems with high renewable energy penetration. We propose an advanced control framework for integrating virtual inertia into voltage source inverters (VSIs) to enhance transient stability and frequency response. Our approach leverages adaptive control strategies and fuzzy logic-based regulation to improve system robustness across various operating scenarios. Through detailed simulations and performance analyses, we compare fixed and adaptive virtual inertia implementations, assessing their effectiveness in maintaining frequency stability.

The following sections of this work are structured as follows: i) Section 2 provides the theoretical background, covering the role of inertia in power system stability and the concept of virtual inertia; ii) Section 3 presents the proposed methodology, including the implementation of adaptive virtual inertia, parameter selection, and the design of membership functions for the fuzzy logic controller; iii) Section 4 discusses the results obtained from simulations; iv) Section 5 provides a detailed discussion and analysis of the findings; finally, v) Section 6 summarizes key conclusions.

2. THEORETICAL BACKGROUND

2.1. The role of inertia in power system stability

In power systems, inertia refers to the resistance against changes in frequency. It's directly linked to the rotating mass of generators connected to the grid, such as turbines in traditional power plants [18], [19]. A higher inertia constant signifies a slower adjustment to frequency deviations but also a larger jump in frequency following a disturbance in the system's balance between power generation and consumption, as shown in Figure 2 [20].

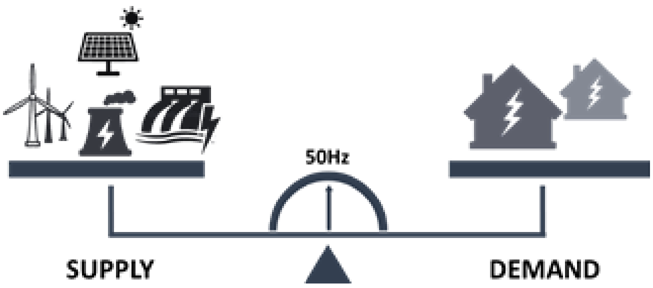

Figure 2. Power generation and load balance

The group turbine-synchronous generator is the foundation of all conventional power plants, including nuclear, hydro, and thermal ones. It rotates as a result of two opposing torques, the mechanical torque Tm of the turbine and the electromagnetic torque Te of the synchronous generator. The mechanical power Pm generated by fossil fuel for conventional power plants, which powers the synchronous generator, represents the first torque, and the power demand of the electrical grid load represents the second torque [21], according to (1).

$$T_m - T_e = \frac{P_m}{\omega} - \frac{P_e}{\omega} \tag{1}$$

Since the turbine-synchronous generator system represents a continuously rotating mass, it stores kinetic energy, denoted as EKinetic.

$$E_{Kinetic} = \frac{1}{2} J \omega^2 \tag{2}$$

Where J denotes the moment of inertia of the system and ω represents the rotor speed, which is directly proportional to the power grid frequency. According to (3), the kinetic energy stored in the rotating mass is released when there is an imbalance between power generation and consumption [21].

$$\frac{dE_{Kinetic}}{dt} = P_m - P_e \tag{3}$$

In the per-unit system, the corresponding equation can be reformulated as (4).

$$\frac{d\omega}{dt} = \frac{P_m - P_e}{2.H.S} \tag{4}$$

Where H denotes the inertia constant, characterizing the energy stored in the rotating masses of the power system, as in (5).

$$H = \frac{E_{Kinetic}}{S} = \frac{1}{2} \cdot \frac{J.\omega^2}{S} \tag{5}$$

The derivative dω/dt denotes the rate of change of frequency RoCoF in the power system. It reflects the dynamic response of the system to imbalances between mechanical power input and electrical power output, essentially, supply and demand. This rate is intrinsically linked to the system's inertia constant H, which governs how severely frequency is affected during disturbances. A power system with higher inertia will exhibit a slower frequency decline, thereby enhancing its stability during such events.

2.2. The concept of virtual inertia

Virtual inertia is a control technique designed to emulate the inertia of traditional synchronous generators in inverter-based renewable energy sources [22]. As the penetration of RESs increases, the overall inertia of the power system decreases, compromising grid stability and reliability [23]. VI-based inverters, including VSM [24], virtual synchronous generators (VSGs) [25], and synchronverters, address this challenge by mathematically emulating the behavior of synchronous generators through pulse-width modulation (PWM) controllers [23]. The implementation of VI control has been shown to enhance frequency stability in interconnected power systems with high RES penetration [26]. Various VI control topologies exist, and their suitability depends on the specific system control architecture and the desired level of replication of synchronous machine dynamics [27]. While VI techniques offer significant promise for maintaining grid stability in high-RES grids, challenges remain regarding system-level integration. Further research is needed to address these integration challenges and optimize VI control strategies for different grid scenarios [27].

To address the challenge of decreasing inertia with increasing renewable energy penetration, virtual inertia offers significant benefits for power systems. VI-based inverters, including VSM, VSG, and synchronverters, can emulate the behavior of traditional synchronous generators. This emulation helps mitigate frequency instability caused by the lack of inherent inertia in solar and wind power systems [23]. VI devices achieve this by providing a faster frequency response and more effective disturbance mitigation compared to traditional droop control. Additionally, VI helps slow down the RoCoF, preventing rapid fluctuations that could lead to grid instability [28]. VI can be implemented through grid-connected power converters, utilizing energy stored in DC-link capacitors to emulate inertia without requiring hardware modifications [29]. Various VI-based inverter systems have been developed, and studies show they can significantly improve frequency stability, with up to a 50% improvement in RoCoF [29]. As renewable energy penetration increases globally, VI strategies are becoming increasingly crucial for maintaining power system stability and reliability [30].

The inertial response is essential for maintaining frequency stability in systems with low rotational inertia, such as those dominated by power electronic interfaces. By countering rapid frequency fluctuations, virtual inertia helps prevent abrupt changes that could destabilize the grid [31]. In contrast, damping mechanisms are designed to attenuate oscillations in the system frequency following disturbances. The damping effect ensures that the system returns smoothly to its steady-state operating point. While virtual inertia addresses the initial response to frequency transients, damping provides long-term stability [32]. Together, these mechanisms are crucial for enhancing the dynamic performance of modern power systems, particularly those with high penetration of renewable energy resources, as illustrated in (3).

$$2H\,\frac{d\omega}{dt} = \frac{P^{ref}-P}{\omega} - K_d\left(\omega - \omega^{ref}\right) \tag{6}$$

Where:
- P and P_{ref} are the measured active power and reference active power.
- $\boldsymbol{\omega}$ and $\boldsymbol{\omega}_{ref}$ denote the measured and reference frequencies, respectively.
- H and K_d denoting the inertia and damping constants, respectively.

3. METHOD

The proposed methodology for implementing virtual inertia involves a VSI control scheme with inner and outer control loops. The outer loop manages active and reactive power references, adjusting voltage and current setpoints based on power measurements. These setpoints are tracked by the inner loop, which includes voltage and current controllers, ensuring accurate output. An adaptive virtual inertia strategy, based on fuzzy logic, dynamically adjusts the inertia constant using real-time measurements of system frequency and the RoCoF. This approach, implemented in MATLAB/Simulink, enhances system stability compared to fixed virtual inertia methods.

The hierarchical control architecture shown in Figure 3, where the outer control loop is responsible for regulating active and reactive power. The active power controller (APC) manages the system's power output by receiving a reference frequency ω^{ref}, power P^{ref}, and then adjusting the phase angle θ, and frequency ω, accordingly to match the power demand. The reactive power controller (RPC) functions similarly but focuses on maintaining the desired reactive power Q^{ref} and voltage reference V^{ref}.

The inner control loop, as shown in Figure 4, is composed of the voltage and current controllers, is tasked with maintaining stable voltage and current levels. The voltage controller adjusts the reference Vo^d, while the current controller tracks the desired current by transforming the dq-axis reference signals back to abc-coordinates, ready for modulation. The pulse-width modulation (PWM) block then converts these signals into switching pulses that control the inverter's operation, ensuring accurate power delivery. Table 1 provides a summary of the system configuration.

3.1. Adaptive virtual inertia implementation

This section provides a qualitative assessment of the proposed virtual inertia-active power controllers across different operational modes and system conditions. The average converter model, previously described, was implemented in MATLAB/Simulink. The APC design is grounded in the concept of virtual inertia, comparing two distinct strategies: the traditional fixed virtual inertia constant (see Figure 5) and an adaptive virtual inertia constant as shown in Figure 6. In the adaptive strategy (see Figure 6), the inertia constant is dynamically adjusted using a fuzzy logic algorithm, which relies on real-time measurements of system frequency and the RoCoF to fine-tune the inertia response.

Table 1. General configuration of voltage source inverter

Parameter	Value
DC voltage	800 V_{DC}
AC voltage	380 V_{AC}
Rated frequency	50 Hz
Rated power	10 kVA
Switching frequency	10 KHz
Voltage PI-controller (proportional)	0.04
Voltage PI-controller (integral)	400
Current PI-controller (proportional)	15
Current PI-controller (integral)	15000

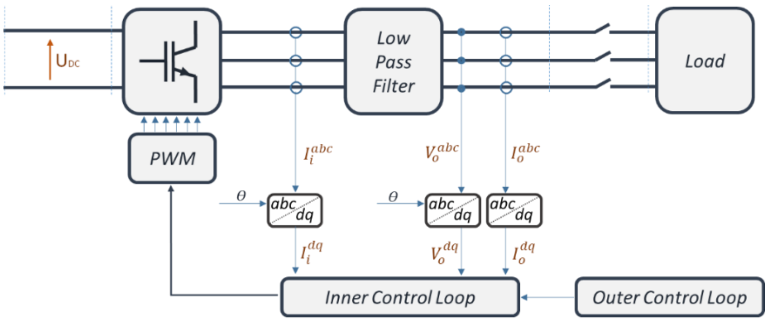

Figure 3. General scheme of voltage source inverter modules

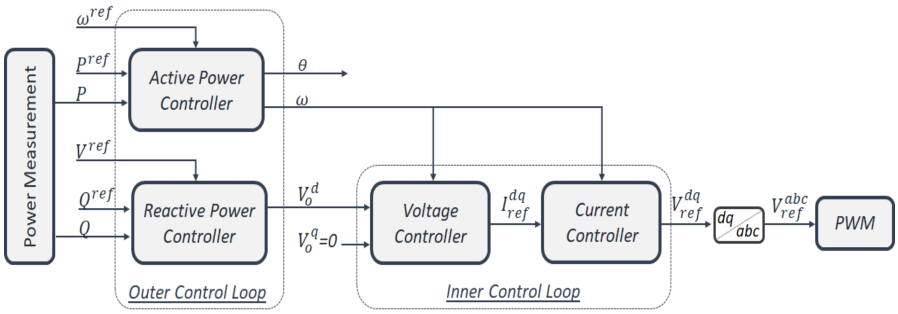

Figure 4. Detailed scheme of inner and outer control loops

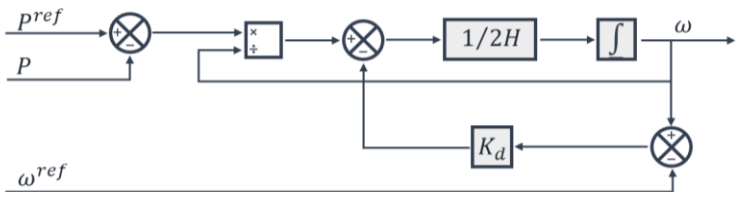

Figure 5. The fixed virtual inertia based active power controller

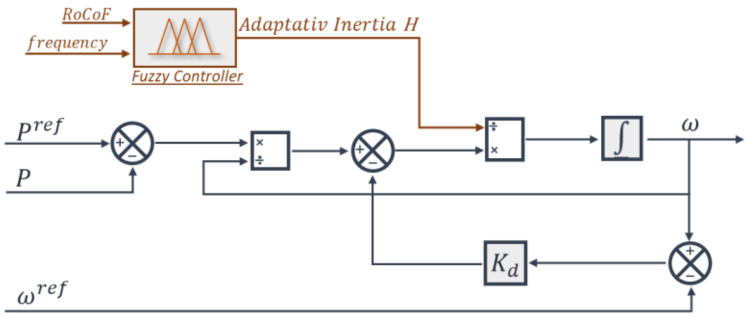

Figure 6. The adaptive virtual inertia based active power controller

3.2. Parameter selection

Experimental studies have shown that choosing a virtual inertia constant H up to 3 seconds ensures a balanced trade-off between system stability and dynamic performance [33], provided it remains above the minimum threshold required for adequate frequency support. Lower values of H, around 0.5 seconds, are suitable for systems that require a faster response, while higher values, approaching 3 seconds, are more appropriate for scenarios where frequency stability is the primary concern. The selection of H should be tailored to the specific characteristics of the system, including its base power, expected power imbalances, and the maximum allowable RoCoF, according to (1).

$$\text{RoCoF} = \frac{\Delta P \, .f_0}{2\,H\,.S} \tag{7}$$

Where

- ΔP is the power imbalance
- H is the system inertia constant
- S is the rated apparent power of the system
- f_0 is the system frequency

The objective of the following section is to implement a controller based on adaptive fuzzy logic, with frequency and ROCOF as inputs, and the virtual inertia constant H as the output. The membership functions and rules governing the system will be described in the following sections.

3.3. Design of function of fuzzy logic controller

The effectiveness of the proposed fuzzy logic controller heavily relies on the proper selection of fuzzy rules [34]. In the designed controller, the system's frequency response follows an underdamped behavior. As depicted in the membership function Figure 7(a), frequency deviations are categorized into three regions: Low, representing frequencies below the nominal range; Nominal, covering the standard operating frequency; and High, indicating frequencies exceeding the nominal value, this classification allows the controller to adaptively adjust virtual inertia to mitigate frequency deviations and enhance system stability. Figures 7(b) and 7(c) illustrates the membership functions for both the RoCoF and virtual inertia, highlighting the distribution of membership functions used in the fuzzy logic-based control approach.

The fuzzy rules are constructed to inject higher virtual inertia during extreme frequency deviations (PH and NH regions), which helps slow the rate of change and stabilize the frequency. Conversely, lower inertia is applied when the frequency moves back towards its nominal value, allowing for quicker recovery. This adaptive approach ensures that virtual inertia is applied proportionally to the severity of the disturbance, improving both frequency stability and system response.

Table 2 detailed description of the proposed range of membership functions for the fuzzy logic controller used to adjust the virtual inertia based on input parameters: The proposed fuzzy logic controller dynamically adjusts virtual inertia H based on the input variables: frequency and RoCoF. Membership functions map these inputs to appropriate inertia levels according to predefined rules in Table 3. For instance, when frequency is low and RoCoF is highly negative, a high H is applied to stabilize the system. Conversely, near-nominal frequency with minimal RoCoF requires a low H. Moderate deviations are managed with medium inertia to balance stability and responsiveness. These real-time adjustments enable the system to adapt seamlessly to fluctuating grid conditions, enhancing overall performance.

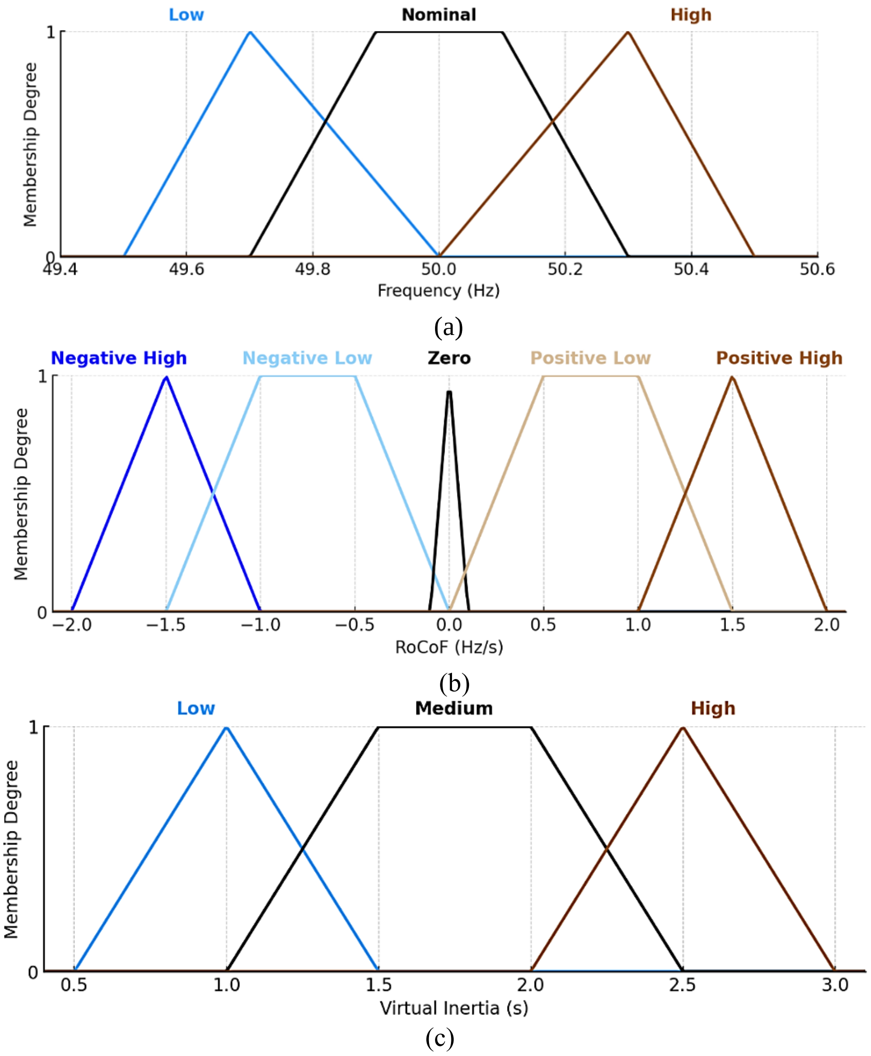

Figure 7. Membership functions of the fuzzy logic controller: (a) input frequency, (b) input RoCoF, and (c) output virtual inertia

Table 2. Proposed range of membership function

Membership function			Range	Units
Input variable	Frequency (f)	Low	[49.5 49.7 50.0]	Hz
		Nominal	[49.7 49.9 50.1 50.3]	
		High	[50.0 50.3 50.5]	
	RoCoF (df/dt)	Negative high	[−2.0 −1.5 −1.0]	Hz/s
		Negative low	[−1.5 −1 −0.5 0]	
		Zero	[−0.1 0 0.1]	
		Positive low	[0 0.5 1 1.5]	
		Positive high	[1.0 1.5 2.0]	
Output variable	Virtual inertia (H)	Low	[0.5 1.0 1.5]	seconds
		Medium	[1.0 1.5 2 2.5]	
		High	[2 2.5 3]	

Table 3. Proposed rules

Virtual inertia H		RoCoF				
		Negative high	Negative low	Zero	Positive low	Positive high
f	High	-	Medium	-	Low	Low
	Nominal	-	Medium	Low	Low	-
	Low	High	Medium	-	Medium	-

4. RESULTS

The study presented a comparative analysis between two control strategies applied to a 10 kW, VSI subjected to a sudden load increase of 5 kW at 0.5 seconds. The first system employed a fixed virtual inertia H=1.5 seconds, while the second system utilized an adaptive virtual inertia control, where the inertia value varied between 0.5 and 3 seconds, depending on system's frequency and RoCoF.

Figure 8 provides critical insights into the system's frequency response. In both cases, the frequency dips following the load increase, but the adaptive virtual inertia system (blue graph) clearly outperforms the fixed inertia case (red graph). The adaptive inertia controller not only reduces the frequency nadir (the lowest point of frequency dip) but also significantly decreases the RoCoF. The lower nadir implies that the system experiences less deviation from its nominal frequency, and the reduced RoCoF ensures a smoother transition during disturbances. This improvement can be attributed to the dynamic adjustment of inertia in the adaptive system, which effectively dampens frequency oscillations during transient events.

The frequency nadir with adaptive inertia is 49.9625 Hz, slightly higher than the 49.9562 Hz achieved by fixed inertia as shown in Table 4, indicating improved resilience against frequency dips. Additionally, the frequency deviation (ΔF) is reduced to 0.0375 Hz with adaptive inertia, compared to 0.0438 Hz for fixed inertia, showcasing better control precision. The overshoot in adaptive inertia is also significantly minimized to 0.0010 Hz, compared to 0.0065 Hz for fixed inertia, emphasizing its superior capability in mitigating abrupt frequency deviations.

Figure 9 illustrates the root mean square (RMS) voltage response of both systems under the applied perturbation. As seen in the graph, the voltage drops slightly around the 0.5-second mark due to the sudden load increase. Both control strategies manage to recover the voltage quickly, with negligible differences in performance. This indicates that, from a voltage stability perspective, both the fixed and adaptive inertia systems are capable of handling sudden load changes effectively. However, voltage recovery alone is insufficient for evaluating system stability, as frequency dynamics play a crucial role in microgrid performance.

During the perturbation, both systems exhibit a transient response in power output as expected. The active power increases proportionally to match the load demand, while the reactive power undergoes minor fluctuations (Figure 10). There is no substantial difference between the fixed and adaptive inertia systems regarding the power balance, confirming that both controllers adequately handle the power dynamics of the system. In contrast, the fixed inertia system maintains a constant inertia value throughout the event, which leads to a slightly more pronounced frequency dip and a higher RoCoF. The adaptive controller's ability to adjust inertia based on the instantaneous system conditions (frequency and RoCoF) allows it to maintain system stability more efficiently, particularly in cases of sudden load variations.

Table 4. Results

Inertia type	Frequency nadir	ΔF	Overshoot
Adaptive inertia	49.9625 Hz	0.0375 Hz	0.0010 Hz
Fixed inertia	49.9562 Hz	0.0438 Hz	0.0065 Hz

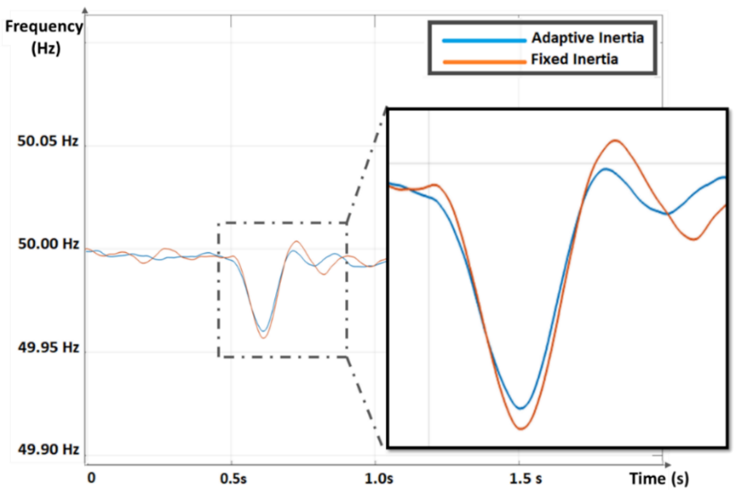

Figure 8. Frequency measurement of fixed inertia VSI (red) and adaptive inertia controller VSI (blue)

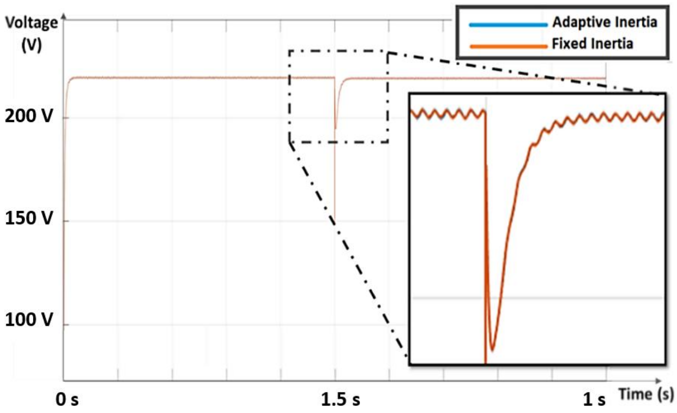

Figure 9. Voltage measurement of fixed inertia VSI (red) and adaptive inertia controller VSI (blue)

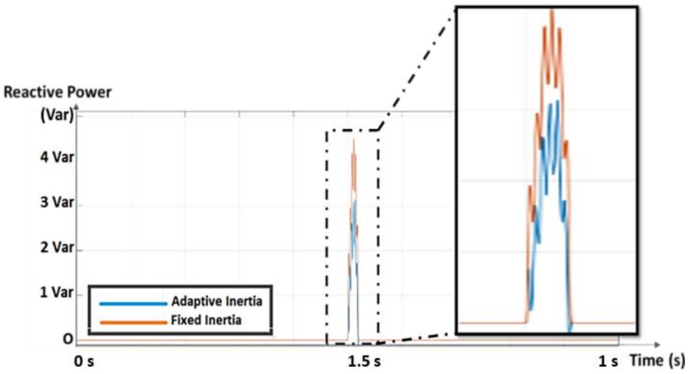

Figure 10. Reactive power measurement of fixed inertia VSI (red) and adaptive inertia controller VSI (blue)

5. DISCUSSION

The rapid growth and integration of renewable energy sources in modern power grids are dramatically reshaping the landscape of energy generation and distribution. This transition, driven by the increasing use of inverter-based resources such as photovoltaic systems and wind turbines, presents both opportunities and challenges for grid stability. The massive integration of these renewables, often interfaced through power electronics rather than conventional synchronous machines, introduces a significant challenge in terms of system inertia. Unlike traditional generators, which inherently provide inertia through their rotating masses, inverter-based renewables offer minimal or no inertia, leading to a faster and more pronounced response to power imbalances in the grid. As a result, frequency stability is becoming a critical concern, especially when faced with sudden load changes or generation fluctuations.

In such low-inertia power systems, the RoCoF becomes a key metric for grid stability. When a power imbalance occurs—whether due to an increase in load or a decrease in generation—RoCoF indicates how quickly the frequency deviates from its nominal value. A high RoCoF suggests that the system is more vulnerable to rapid frequency drops, increasing the risk of instability or even grid failures. As renewable penetration increases, RoCoF is evolving to become a primary parameter for grid requirements, with grid operators around the world setting stricter limits on RoCoF to ensure secure operation. For example, many grid codes mandate that RoCoF should remain below 1 to 2 Hz/s during disturbances to allow sufficient time for corrective measures. The challenge is further amplified in microgrids, where the system's resilience to frequency disturbances is crucial. In these systems, the frequency drop requirement is often set to be within ±0.2 Hz to ±0.5 Hz under normal operating conditions and may allow deviations of up to ±1 Hz during disturbances. When the frequency deviation exceeds these limits, the microgrid employs mechanisms such as under-frequency load shedding (UFLS) to maintain system stability. Furthermore, RoCoF in microgrids is typically constrained to a range of 0.5 Hz/s to 2 Hz/s for safety and operational reliability, with more conservative grids operating at even lower limits, around 0.1 Hz/s to 0.2 Hz/s.

Addressing these evolving grid requirements, this work focuses on the implementation of adaptive virtual inertia in voltage source inverters (VSIs) to improve their response to frequency nadir and RoCoF. The adaptive virtual inertia controller dynamically adjusts the inertia constant H in response to real-time measurements of frequency and RoCoF, enabling the system to provide additional inertia during periods of significant power imbalance. Through simulations, it was observed that adaptive virtual inertia reduces the vulnerability of VSIs to power imbalances, particularly by mitigating RoCoF and minimizing the frequency nadir. Both fixed and adaptive virtual inertia systems were tested under a scenario where a 10 kW VSI experienced a sudden load increase of 5 kW at 0.5 seconds. In the case of the VSI with adaptive inertia (ranging from 0.5 to 3 seconds), the system exhibited a more controlled frequency response with a shallower frequency nadir and lower RoCoF compared to the fixed inertia system (H = 1.5 seconds). These results demonstrate that incorporating adaptive virtual inertia can significantly enhance the resilience of inverter-based systems by providing a dynamic response to grid disturbances, contributing to improved frequency stability in low-inertia grids. This study aligns with ongoing efforts to redefine grid stability in the era of high renewable penetration, particularly as the frequency nadir and RoCoF become critical parameters in meeting evolving grid requirements. By adapting the inertia in real time, power systems can better handle fluctuations, ultimately reducing the risk of instability and helping ensure the secure operation of microgrids and larger grids alike.

6. CONCLUSION

This study investigates the dynamic performance of two voltage source inverters (VSIs) equipped with different virtual inertia control strategies under a step change in load. Both systems were designed with identical parameters and fed identical 10 kW loads at 400 V. The primary distinction between the two systems lies in their virtual inertia control approaches. The first VSI employed a conventional fixed virtual inertia control strategy, while the second implemented an adaptive virtual inertia control scheme. The adaptive strategy dynamically adjusted the virtual inertia value based on real-time measurements of frequency and its derivative. Both systems were subjected to a 50% step increase in load to assess their transient response and stability.

The frequency response of both VSIs to the load perturbation shows a transient drop, as expected, due to the increased power demand. However, a notable disparity in their dynamic behavior was observed. The VSI with the adaptive virtual inertia exhibited a superior transient response. The frequency dip was less pronounced, and the system returned to the nominal frequency more rapidly with minimal oscillations. Conversely, the VSI with the fixed virtual inertia displayed a larger frequency overshoot and a slower recovery time.

The enhanced performance of the adaptive inertia system can be attributed to its ability to dynamically adjust the virtual inertia value in response to changing system conditions. This allows for a more precise and tailored damping of frequency oscillations, thereby improving system stability and dynamic performance. The fixed inertia system, on the other hand, is limited by a pre-determined inertia value, which may not be optimal for varying load conditions.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Rafik Lasri	✓	✓			✓				✓	✓		✓	✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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