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STABLE ASSESSMENT OF INTEGRATED AC/DC MICROGRIDS FOR TWO WAY POWER FLOW THROUGH THE INTERCONNECTED CONVERTERS

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ABSTRACT

The rapid integration of renewable energy sources and energy storage systems has led to the rise of integrated AC/DC microgrids, which combine alternating current (AC) and direct current (DC) networks for greater efficiency and flexibility. A key challenge in these systems is ensuring stable two-way power flow between AC and DC subsystems through interconnected converters. This paper presents a stable assessment of integrated AC/DC microgrids, focusing on maintaining system stability during bidirectional power transfer under varying load conditions and intermittent renewable generation. The assessment explores different converter configurations, control strategies, and stability criteria that ensure balanced power-sharing, voltage regulation, and frequency control across the AC and DC networks. By analyzing the stability margins and response to dynamic changes in power demand and supply, the paper demonstrates that advanced control mechanisms can ensure a smooth and stable operation of hybrid microgrids. Simulation results confirm the effectiveness of these strategies in maintaining grid stability while enhancing system efficiency, fault tolerance, and resilience. The findings underscore the critical role of stability in enabling the successful deployment of AC/DC microgrids for decentralized energy systems and modern smart grids.

Keywords: *Integrated AC/DC Microgrids, Two-Way Power Flow, Interconnected Converters, Stability Assessment, Power Management, Hybrid Energy Systems, Smart Grids.*

INTRODUCTION:

As the integration of renewable energy sources and energy storage systems becomes increasingly prevalent, the design and operation of integrated AC/DC microgrids have emerged as a viable solution for enhancing the flexibility and reliability of modern power systems. However, a significant challenge in these microgrids is ensuring stable two-way power flow between AC and DC networks through interconnected converters [1]. Traditional power systems have primarily operated on either AC or DC configurations, leading to inefficiencies and limitations in energy management. The transition to hybrid AC/DC microgrids introduces complexities related to power sharing, voltage and frequency regulation, and the dynamic behavior of interconnected converters. Fluctuating generation from renewable sources and variable load demands further complicate the maintenance of system stability. Therefore, there is a critical need to assess the stability of integrated AC/DC microgrids under various operating conditions, focusing on: Control Strategies: Developing effective control algorithms to ensure seamless coordination between AC and DC converters, enabling reliable power exchange. Voltage and Frequency Regulation: Maintaining stability during bidirectional power flow, particularly under varying load conditions and intermittent renewable generation. Dynamic Response: Analyzing the system's ability to respond to sudden changes in power demand or supply while preventing instability and outages [2]. This research aims to address these challenges by providing a comprehensive assessment of the stability of integrated AC/DC microgrids, ultimately contributing to the development of more resilient and efficient energy systems that can meet the demands of a decentralized energy future [3]. The ongoing transition toward sustainable energy systems has driven the integration of renewable energy sources, such as solar and wind, into the electrical grid. As a result, the concept of integrated AC/DC microgrids has gained prominence, offering a versatile solution for managing both alternating current (AC) and direct current (DC) power. These microgrids enable improved energy efficiency, flexibility, and resilience by facilitating the seamless integration of distributed energy resources (DERs), energy storage systems, and electric vehicles. A critical feature of integrated AC/DC microgrids is their capability for two-way power flow through interconnected converters [4]. This bidirectional flow allows energy to be exchanged between AC and DC networks, enhancing the overall

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performance of the system. However, the complexity introduced by this hybrid architecture poses significant challenges, particularly in maintaining stability during dynamic operating conditions. Fluctuations in renewable energy generation, varying load demands, and potential disturbances can jeopardize the stable operation of the microgrid. This paper aims to provide a comprehensive assessment of the stability of integrated AC/DC microgrids, focusing on the interactions between AC and DC subsystems and the role of interconnected converters in managing two-way power flow. By analyzing various converter topologies, control mechanisms, and stability criteria, this research seeks to enhance our understanding of how to optimize the operation of hybrid microgrids. The findings will contribute to the development of more resilient energy systems capable of supporting the increasing penetration of renewable resources while ensuring stable and reliable power delivery.

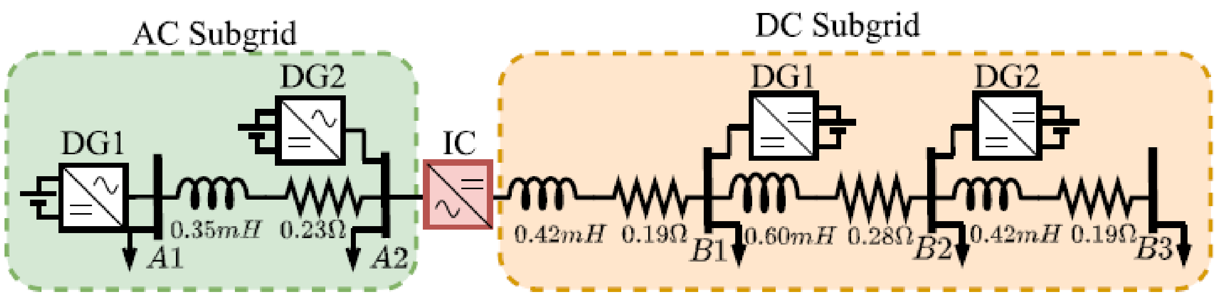

Figure1: Design of Integrated AC-DC-microgrid

LITERATURE SERVEY

The evolution of integrated AC/DC microgrids has garnered significant attention in recent years, driven by the need for enhanced energy efficiency and reliability in the context of increasing renewable energy integration. This literature review highlights key studies and advancements related to the stable assessment of integrated AC/DC microgrids, particularly focusing on two-way power flow through interconnected converters. Recent works have explored various architectures of integrated AC/DC microgrids, emphasizing their ability to facilitate the coexistence of AC and DC power systems [5]. Research indicates that hybrid configurations can effectively manage energy flows from diverse sources, improving overall system efficiency and reducing losses associated with power conversion. Studies highlight the benefits of using a combination of AC and DC buses to accommodate different types of loads and generators, thereby enhancing the system's operational flexibility. The role of interconnected converters in enabling two-way power flow is critical for the operation of AC/DC microgrids. Research has focused on different converter topologies, such as DC-DC converters, AC-DC converters, and bidirectional converters, that facilitate seamless energy exchange between AC and DC networks [6]. Advanced control strategies, including model predictive control (MPC) and fuzzy logic control, have been proposed to optimize power-sharing and ensure stable operation during varying load and generation conditions. Stability assessment is a primary concern in the operation of integrated AC/DC microgrids. Numerous studies have investigated the stability of hybrid systems using various analytical and simulation-based approaches [7]. Techniques such as Lyapunov stability theory, small-signal stability analysis, and root locus methods have been employed to evaluate the dynamic performance of interconnected converters under different operating scenarios. Researchers have developed robust control schemes to ensure voltage and frequency stability, addressing the challenges posed by bidirectional power flow and fluctuations in renewable generation. Maintaining voltage and frequency stability in integrated AC/DC microgrids is essential for reliable operation [8]. Several studies have focused on control algorithms that regulate voltage levels across AC and DC buses, ensuring balance and preventing cascading failures. Research has shown that effective voltage regulation techniques, such as droop control and participation factor methods, can significantly enhance the stability of microgrid operations while accommodating the variability of renewable energy sources. The dynamic performance of integrated AC/DC microgrids is a critical area of research, particularly regarding their ability to respond to sudden changes in generation and load. Studies have highlighted the importance of resilience in microgrid design, showcasing strategies that enable rapid recovery from disturbances and maintain stable operation. The integration of energy storage systems (ESS) has been identified as a key factor in improving dynamic response and providing backup power during outages, further enhancing the stability of the microgrid. The literature emphasizes the significant advancements in the understanding and assessment of integrated AC/DC microgrids, particularly concerning the stability of two-way power flow through interconnected converters. Ongoing research continues to refine control strategies, enhance converter designs, and develop methodologies for stability assessment, all contributing to the successful deployment of hybrid microgrid systems. As the demand for renewable energy integration increases, the findings from these studies will play a vital role in guiding the development of more efficient, reliable, and resilient AC/DC microgrid solutions.

METHODOLOGY:

The proposed methodology outlines the systematic approach used to assess the stability of integrated AC/DC microgrids, focusing on the dynamics of two-way power flow through interconnected converters.

Stable Assessment Of Integrated Ac/Dc Microgrids

The stability margin of the HMG is characterized by the maximum power transfer capability of the ICs and the critical droop gains of the DGs. In the following subsections, the dc to ac subgrid power flow (0.5 p.u), zero power flow, and ac to dc subgrid power flow (−0.5 p.u) conditions are considered. Firstly, let us consider the loci of the dominant modes to changes in the droop gains (mac = mdc). By constantly increasing the droop gains from a value of 0.02 p.u, Fig. 8 shows that mode 1 moves towards the right-half plane. However, for the condition in Fig. 8a where 0.5 p.u flows from dc to ac subgrid, the HMG dominant modes remain in the left-half plane and retain the system stability when mac = mdc ≤ 0.034 p.u. Thus, the stability margin for this condition is given as 0.034 p.u. Furthermore, Fig. 8b shows a trace of the dominant modes when there is no power transfer between both subgrids. By increasing the droop gains, the system becomes unstable when mode 1 crosses the imaginary axis at mac = mdc = 0.029 p.u, which dictates. The stability margin for this operating condition. In addition, as depicted in Fig. 8c, the dominant modes, for scenario 4, reside in the right-half plane and the HMG becomes unstable for the droop gain mac = mdc = 0.025 p.u, which defines the stability margin for this scenario. It can be observed. Under inverter operation, the current paths are different because the currents flowing through the transistors come mainly from the dc capacitor CD. Under rectifier operation, the circuit works like a Boost converter, and under inverter operation it works as a Buck converter. To have full control of the operation of the rectifier, their six diodes must be polarized negatively at all values of instantaneous ac voltage supply. Otherwise, the diodes will conduct, and the PWM rectifier will behave like a common diode rectifier bridge. The way to keep the diodes blocked is to ensure a dc link voltage higher than the peak dc voltage generated by the

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diodes alone. In this way, the diodes remain polarized negatively, and they will conduct only when at least one transistor is switched ON, and favorable instantaneous ac voltage conditions are given.

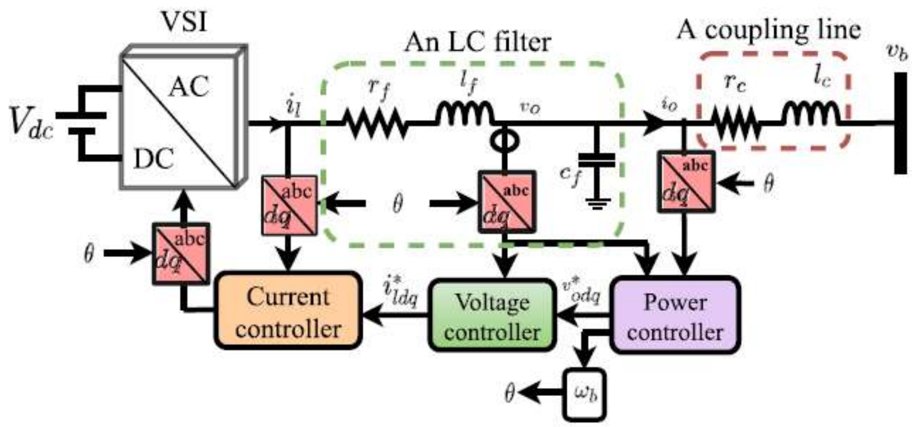

Figure2: Proposed Methodology of AC-DC-microgrid

Two Way Power Flow Through The Interconnected Converters

This methodology outlines the systematic approach to designing, implementing, and assessing integrated AC/DC microgrids that facilitate two-way power flow through interconnected converters. The focus is on optimizing performance, ensuring stability, and effectively managing the complexities of hybrid power systems. Identify key components, including renewable energy sources (solar panels, wind turbines), energy storage systems (batteries, supercapacitors), loads, and converters (AC-DC, DC-DC). Design the architecture of the microgrid, defining the interconnections between AC and DC buses, and determining the locations of converters to facilitate optimal power flow. Utilize simulation tools such as MATLAB/Simulink or PSS/E to create a virtual environment for testing the integrated microgrid under various operational scenarios. Design and configure converters to support two-way power flow, ensuring they can efficiently handle energy transfer in both directions between AC and DC systems. Implement power-sharing strategies to maintain equilibrium between AC and DC buses, preventing overloads and ensuring stable operation. Conduct stability analysis using methods such as Lyapunov stability criteria and small-signal analysis to evaluate the microgrid’s ability to maintain stable operation under various disturbances. This methodology provides a comprehensive framework for the design, implementation, and assessment of integrated AC/DC microgrids, focusing on two-way power flow through interconnected converters. By systematically addressing each aspect of the microgrid operation, the methodology aims to enhance reliability, efficiency, and stability, ultimately contributing to the advancement of smart and sustainable energy systems.

RESULT ANALYSIS:

The power transfer between two adjacent ac and dc subgrids depends on the droop characteristics of DGs and ICs . In sharing the load among droop-based ac and dc subgrids interfaced in an HMG, the dominant values are largely affected by the frequency droop gains in comparison with those of the dc voltage. During the inverting mode of ICs, the power angles of the ac DGs are not required to increase as much as in the case of stand-alone ac subgrid to supply the same amount of ac load increase. Additionally, due to the nature of the dc systems, the movement of the values related to the dc subgrid is observed to be neither as fast nor as sensitive as those of the ac subgrid. Therefore, although the values of the dc subgrid move slightly to the right when supplying the ac subgrid, the dominant dynamics of the combined HMG are still related to those of the dc subgrid. Thus, the frequency and angle stability are less likely to arise during the inverting mode of ICs. On the other hand, during the rectifying mode of ICs, the droop-based DGs in the ac subgrid further expand their power angles in order to supply the requested power by the dc subgrid.

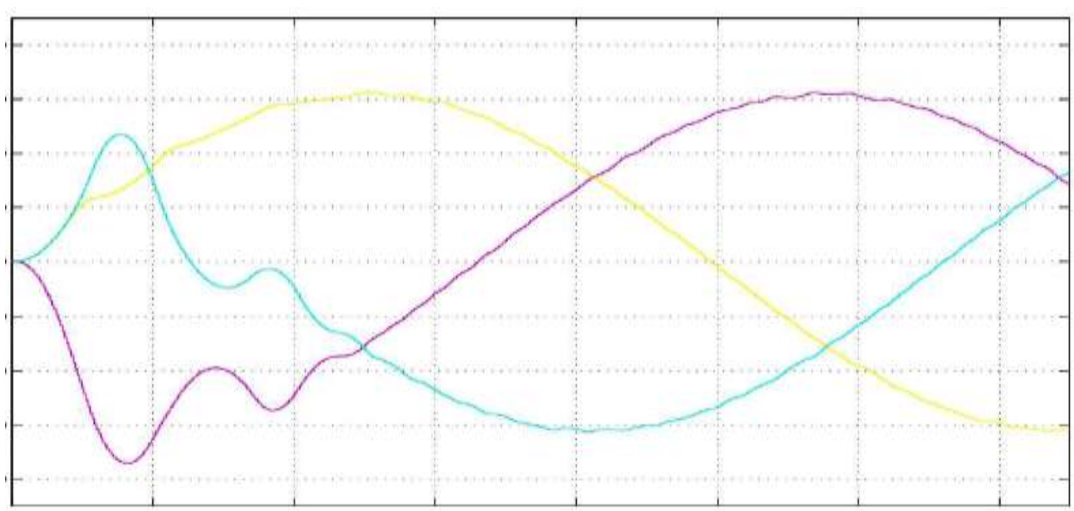

Figure3: Two Way Power Flow through The Interconnected Converters

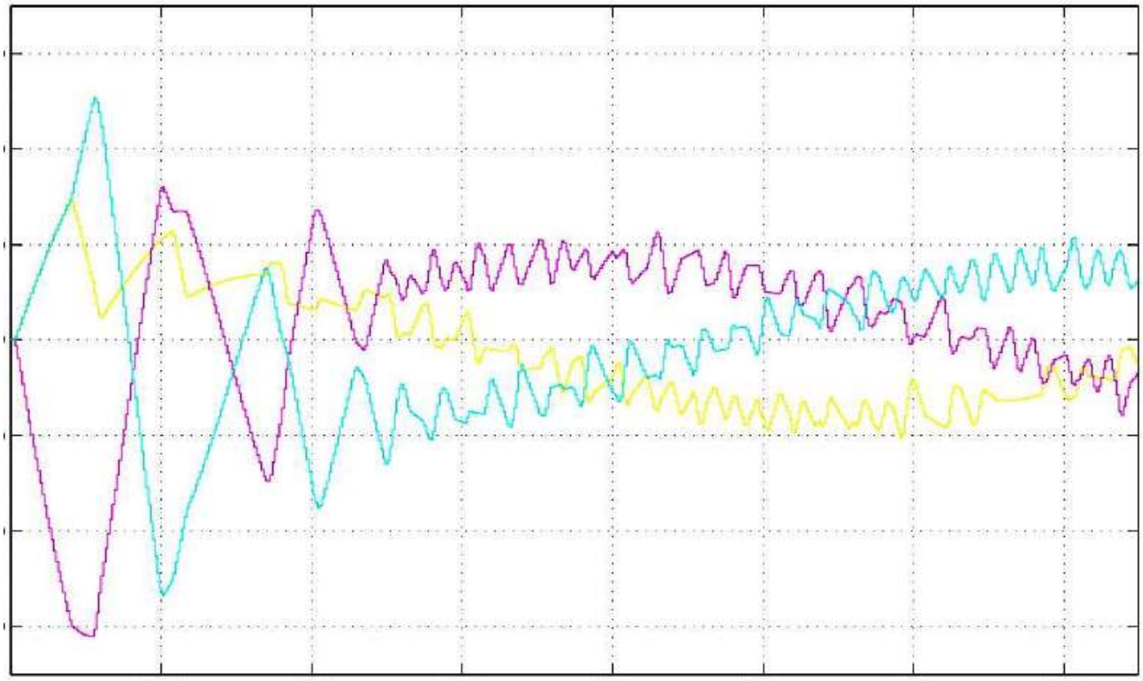

Figure4: Evaluation of Two Way Power Flow

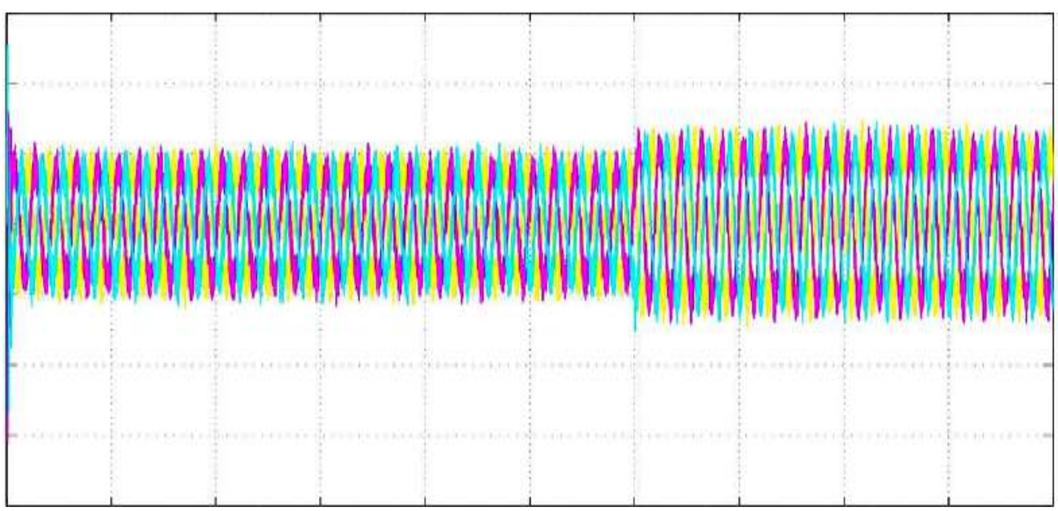

Figure5: Integrated AC/DC Microgrids Grid constancy

CONCLUSION:

The stable assessment of integrated AC/DC microgrids is crucial for effectively managing the complexities introduced by two-way power flow through interconnected converters. This study highlights the significant advancements in understanding and optimizing the operation of hybrid microgrids, particularly in the context of integrating renewable energy sources and ensuring reliability under dynamic conditions. Integrated AC/DC microgrids demonstrate a substantial capacity to manage diverse energy resources, enabling efficient energy distribution tailored to varying loads and generation profiles. Overall, the insights gained from this assessment underscore the potential of integrated AC/DC microgrids to contribute to a more resilient and efficient energy future. Continued research in this area is essential to refine control strategies, improve converter technologies, and enhance stability mechanisms, ultimately facilitating the seamless integration of renewable energy resources into modern power systems. As the global shift towards sustainable energy progresses, the development of stable and reliable microgrid solutions will play a vital role in meeting the challenges of energy management in a decentralized environment.

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