A REVIEW ON HYBRID AC-DC MICROGRID OPERATION STRATEGIES

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Abstract: *With the increasing integration of diverse energy sources and the growing complexity of modern power systems, the need for effective management strategies is paramount. The review critically analyzes existing approaches, highlighting their strengths and identifying areas for improvement. It explores the challenges associated with hybrid microgrid operation, such as seamless power flow coordination between AC and DC components, voltage stability, and adaptive control mechanisms. By synthesizing findings from recent research and technological developments, the review aims to provide a thorough understanding of the current state-of-the-art strategies. Additionally, it discusses potential avenues for future research, emphasizing the importance of advancing coordination and control techniques to enhance the efficiency, reliability, and resilience of hybrid AC-DC microgrid systems.*

Keywords: *Hybrid microgrid, AC-DC integration, Coordination strategies, Control strategies, Microgrid operation.*

I. INTRODUCTION

Cloud storage, the integration of renewable energy sources and the increasing demand for efficient energy management have led to the emergence of hybrid AC-DC microgrids as a promising solution for enhancing the resilience and sustainability of power systems. In this context, a comprehensive review of coordination and control strategies becomes paramount to understand the intricate dynamics and optimize the operation of these complex energy networks.

This review aims to delve into the multifaceted realm of hybrid AC-DC microgrid operation, focusing specifically on the coordination and control strategies employed to ensure seamless integration, stability, and reliability. As the energy landscape undergoes a transformative shift, the challenges associated with diverse energy resources, variable loads, and dynamic grid conditions necessitate innovative and adaptive control approaches.

Throughout this review, we will explore the fundamental principles underlying the coordination of AC and DC components within a hybrid microgrid. The interplay between various control strategies, such as hierarchical control, decentralized control, and optimization-based techniques, will be examined in detail. Insights into the advancements in communication protocols, sensing technologies, and real-time monitoring systems that facilitate effective coordination and control will be elucidated.

Additionally, the review will highlight case studies and practical applications, shedding light on successful implementations and identifying potential areas for further research. By synthesizing the existing knowledge and presenting a comprehensive overview, this review aims to contribute to the evolving discourse on hybrid AC-DC microgrid operation, offering a valuable resource for researchers, practitioners, and policymakers in the field of smart grid technology and renewable energy integration.
As electric distribution technology advances throughout the twenty-first century, numerous developments emerge that will alter the needs for energy supply. These changes are being pushed by both the demand side, where more energy availability and efficiency are sought, and the supply side, where the integration of distributed generation and peak-shaving technology must be accommodated [1], [2]. Power systems are presently undergoing significant changes in operational requirements, mostly as a consequence of deregulation and an increase in the quantity of distributed energy resources (DER). In many instances, DERs incorporate various technologies that enable small-scale generation (micro sources), and some of them make use of renewable energy resources (RES) such as solar, wind, or hydro energy. Having micro sources near to the load reduces transmission losses while also avoiding network congestion. Furthermore, the possibility of end-customers connected to a low voltage (LV) distribution grid (230 V in Europe and 110 V in the US) experiencing power outages is reduced because adjacent micro sources, controllable loads, and energy storage systems can operate in the islanded mode in the event of severe system disturbances. This is currently referred to as a microgrid. A typical microgrid is shown in Figure 1. The unique microgrid is around the size of a low voltage distribution feeder and will seldom surpass a capacity of 1 MVA and a geographic span of 1 km. More than 90% of low voltage residential consumers are served via subterranean cable, with the remainder served by overhead lines. Customers are often supplied with both electricity and heat via microgrids, which use combined heat and power plants (CHP), gas turbines, fuel cells, photovoltaic (PV) systems, wind turbines, and other technologies. Batteries and flywheels are common components of

energy storage systems [3]–[5]. The storing device in a microgrid is analogous to the rotating reserve of big generators in a traditional grid, which maintains the balance of energy production and consumption, particularly during fast fluctuations in demand or generation [6]–[8].

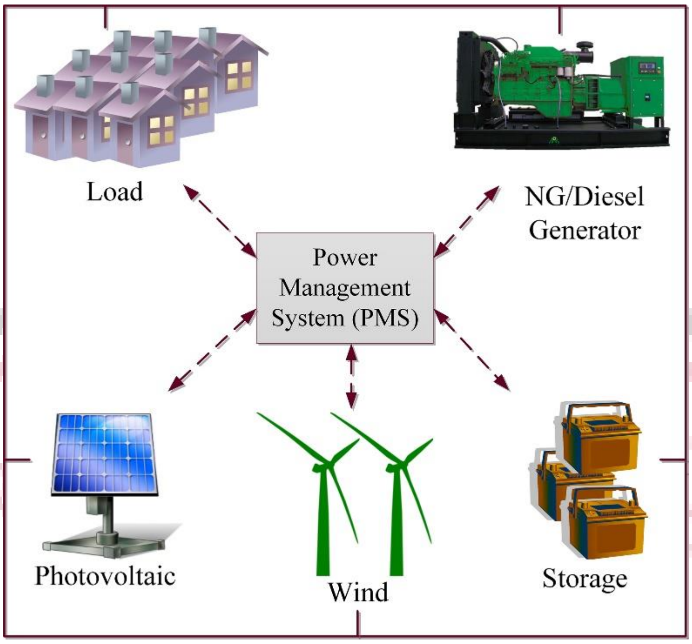

Figure.1. Microgrid power system

The technical difficulties associated with the operation and management of microgrids are enormous. Maintaining stability and power quality in the islanding mode of operation requires the development of advanced control methods for microgrid inverters in order to offer steady frequency and voltage in the face of arbitrarily changing loads [9]. In light of this, the microgrid idea has piqued the interest of numerous academics as well as governmental agencies in Europe, the United States, and Japan. Nonetheless, there are a number of technical problems that must be addressed in the integration and operation of microgrids.

II. LITERATURE REVIEW

Feng Gao et al. [9] Focuses on the hybrid AC/DC microgrid's construction and control method. The photovoltaic (PV) panel, battery, DC load, AC load, induction motor, and numerous converters comprise the AC/DC hybrid microgrid under discussion. Maximum power point tracking (MPPT) technology is used to maximize the output power of PV, the battery, and a bidirectional DC/DC converter with two loops control to regulate the DC bus voltage, and a DC/DC buck converter with a similar control technique to assist regulate the voltage of the DC load. In addition, the controller of the three-phase AC/DC converter that links the AC and DC subgrids in a hybrid microgrid is developed. In grid- connected mode and islanded mode of microgrid, different control methods are utilized for the converter. Finally, a hybrid microgrid model is created in Matlab/Simulink, and the outcomes in grid-connected and isolated modes are evaluated. The findings indicate that while the hybrid grid runs under changing load and weather circumstances, the control approach can keep the hybrid AC/DC microgrid stable.

Ling feng Kou at al. [10] The AC-DC hybrid microgrid is built in this article to achieve unified monitoring and management of energy flow of energy storage station, distributed photovoltaic, AC/DC load, and other units. Grid electricity and distributed photovoltaic are the primary power sources for AC and DC loads. The backup support for AC and DC microgrids is provided by the energy storage power plant. It receives the power grid dispatching automation system in a unified manner, achieves optimum resource allocation, and guarantees the dependable power supply of AC and DC loads. This article proposes two grid structure design methods for AC-DC hybrid microgrids. By comparing its economy and reliability, the scheme of AC-DC hybrid microgrid is improved. Due to the high dependable power supply requirement of secondary devices in data centers and substations, microgrid protection and operation mode switching simulations are performed to validate the scheme's efficacy.

Heng Du et al. [11] Author proposes an AC-DC -V dc 2 droop control strategy applied to the energy router to solve the problem of power energy coordinated management, control, and quality in the AC-DC interconnected Microgrid system.

The approach is derived from the conventional -P droop control scheme in AC Microgrid and the V dc - P droop control scheme in DC Microgrid. When combined with the square value of DC voltage and AC frequency characteristics to regulate the flow direction and amount of power, it achieves bidirectional stable energy transmission of AC-DC Hybrid Microgrid and ensures the energy balance of Microgrid networks.

Pengfei Tu et al. [12] Due to the low loss and cheap cost of removing superfluous energy conversion steps, hybrid AC/DC microgrids have received a lot of attention in recent years. However, owing to the large number of susceptible power converters utilized, the primary issue is the dependability of the microgrid. Power supply interruption caused by power converter failure may substantially raise system operating costs. As a result, microgrid dependability modeling and improvement are critical for lowering microgrid operating costs. Without taking into account the underlying structure of power converters, an oversimplified constant failure rate is often employed to describe renewable energy sources and the interface power converter. This study suggested a hierarchical reliability modeling approach for microgrids to solve this problem. The technique begins with power converter reliability modeling that takes into account the layout of power semiconductors as well as the loading situation. The dependability block diagram is used to represent the microgrid's core structure. The effect of redundant power converter designs on microgrid dependability is also addressed. A case study is carried out to illustrate the use of the suggested approach. The comprehensive reliability study of the microgrid acquired aids in the modeling of power distribution system dependability and the design of microgrid systems.

Hao Zheng et al. [13] Traditional AC micro-grids are unable to satisfy the need for system load variety and economy as DC loads rise. Furthermore, the distributed generation (DGrandom,)'s time-varying, and nonlinear features make DG modeling and algorithm implementation challenging, and coordination and collaboration between DG and energy storage (ES) complicated. This study constructed a hybrid AC/DC micro-grid that includes a DC distribution grid. The appropriate physical model components and control method were presented. This paper's experiment focuses on the study of micro components under various operating circumstances. The findings indicate that the suggested hybrid AC/DC micro-grid structure is acceptable, and the control method and component performance are satisfactory. The whole system has a quick reaction time and can easily meet the system security and stability requirements.

A. A. Eajal et al. [14] An AC/DC hybrid topology is a potential design for future smart grids since it allows for the integration of AC/DC energy supplies with contemporary loads, allowing for the creation of AC/DC hybrid microgrids (HMGs). Understanding AC/DC HMGs and their operating principles during islanding will undoubtedly pave the road for the implementation of a future smart grid with a plug-and-play capability. The design and operation of such isolated and hybrid systems, on the other hand, rely on a strong and efficient power flow instrument. In order to do this, this article presents a new unified, general, and adaptable power flow method for isolated AC/DC HMGs. The power flow subproblems associated with AC and DC subgrids are theoretically represented by a combination of linear and nonlinear equations and solved concurrently using the Newton trust-region technique. The suggested method is general in the sense that it takes into account the unique features of islanded AC/DC HMGs, such as a range of potential topologies, DR droop controllability, and bidirectional power flow in the interlinking converters (ICs). The new power flow formulation is adaptable, allowing for the simple integration of changes in DR operating modes and IC management methods. The proposed method was evaluated and used to analyze selected operational and control features of isolated AC/DC HMGs, such as incorrect power sharing and interlinking converters with varying control strategies. The suggested load flow program may serve as the foundation for and guide future research on isolated AC/DC HMGs.

Wenjiao Guo et al. [15] Due to its bidirectional power flow and unit power factor on the AC side, a three phase AC/DC converter based on conventional double loop control may serve as a link bridge in a hybrid micro-grid. When the AC/DC converter operates with an imbalanced voltage on the AC side, a second order ripple voltage is produced in the DC-link and some third harmonic current exists on the AC side, which may impair the functioning of the micro-grid. A three-phase AC/DC converter system based on super capacitor compensation is provided after evaluating the power flow under unbalanced voltage situations. During the super capacitor's operation, the system may ensure that the AC current is sinusoidal and symmetrical, and that the DC-link voltage fluctuates only little around the rating. The super capacitor reduces active power ripple by acting as an energy buffer. The simulation and experimental findings are given to validate the control system's viability.

Rahul Anand Kaushik et al. [16] As traditional power generating units face problems such as fossil fuel depletion, distributed renewable energy resources (DER)-based power generation has received a lot of attention in recent years. The hybrid AC-DC microgrid not only enables changeable dispersed AC and DC resources to be connected to utilities, but it also eliminates repeated conversions in individual AC or DC microgrids. In this article, a Master-Slave control method for smooth power transfer between AC and DC grids is presented, which is suitable for both grid linked and island mode. MATLAB simulink was used to simulate a hybrid AC-DC microgrid. The simulation findings verify the control system for dependable and stable grid functioning under a variety of load and supply circumstances.

Nabil Qachchachi et al. [17] The optimum power flow management for a hybrid ac/dc microgrid is presented in this article. The goal of this work is to design, model, and control a smart hybrid ac/dc microgrid in grid-tied mode and islanding mode that can exchange data via smart grid bus communication to receive grid power references, manage the power flow between the various sources locally, and facilitate the connection of various ac and dc renewable sources and loads. In this context, a Hybrid Control System (HCS) was designed to maintain power balance in the proposed system's real-time operation.

A. Mohamed at al. [18] Author investigates the different problems that may occur when a bi-directional AC-DC/DC-AC converter connects a DC microgrid to the main AC grid. Furthermore, this converter's protection against line-line, line-ground, one phase open, and DC bus faults is created, presented, and analyzed. The converter proved to be a highly efficient instrument for rapidly transferring any required quantity of power from one side to the other. However, because of its significance, it must be carefully guarded. The fault current via the converter for any fault on the alternating current side was determined to be no more than 2-4 p.u. This is due to the filter's impedance, which restricts the fault current. This increases the difficulty of identifying the problem using the current amplitude. However, another quantity, such as the zero-sequence current, may be utilized to identify this problem. For a problem on the DC side, on the other hand, the charged capacitor discharges in a very short period. As a result, the derivative of the current may be utilized to identify a problem. This paper has a thorough explanation of these topics.

Several researchers have extensively investigated control strategies in hybrid AC-DC microgrid operation to address the challenges of integrating diverse energy sources and ensuring efficient system operation [19]–[24].

III. COMPARATIVE ANALYSIS

A comparative analysis of coordination and control strategies in hybrid AC-DC microgrid operation is crucial for understanding the strengths, weaknesses, and potential improvements in existing approaches. This comparative examination allows researchers and practitioners to make informed decisions on the most suitable strategies for specific applications. Here, we will outline key elements of such a comparative analysis:

Hierarchical vs. Decentralized Control:

Evaluate the performance of hierarchical control structures against decentralized control approaches in terms of system stability, response time, and scalability.

Assess the trade-offs between centralized decision-making and distributed autonomy, considering factors such as communication overhead and fault tolerance.

Optimization-Based Techniques:

Compare optimization-based control strategies, such as model predictive control and evolutionary algorithms, in terms of computational efficiency and effectiveness in handling dynamic microgrid conditions.

Analyze the adaptability of these techniques to varying renewable energy generation patterns and load demands.

Communication Protocols:

Investigate different communication protocols (e.g., wired, wireless, or hybrid) used for information exchange in the coordination and control of hybrid AC-DC microgrids.

Assess the impact of communication delays, reliability, and security on the overall system performance.

Real-Time Monitoring and Sensing Technologies:

Examine the role of real-time monitoring and sensing technologies in enhancing the accuracy of control strategies.

Compare the benefits and challenges associated with various sensor types and their impact on the robustness of microgrid operation.

Case Studies and Practical Implementations:

Analyze case studies that highlight successful implementations of coordination and control strategies in real-world hybrid AC-DC microgrids.

Identify common challenges faced in different scenarios and the adaptability of strategies to diverse operating conditions.

Integration of Energy Storage Systems:

Evaluate how coordination and control strategies accommodate the integration of energy storage systems, considering the type (batteries, supercapacitors) and capacity.

Investigate the impact on system stability, response to fluctuations, and overall efficiency.

Economic and Environmental Metrics:

Compare the economic viability and environmental impact of different coordination and control strategies, considering factors such as investment costs, energy efficiency, and greenhouse gas emissions.

By conducting a comparative analysis across these dimensions, stakeholders can gain valuable insights into the performance characteristics of various coordination and control strategies in hybrid AC-DC microgrid operation. This knowledge can inform future research directions and guide the practical implementation of these strategies in diverse energy scenarios.

IV. DISCUSSION AND FINDINGS

In the comprehensive review of coordination and control strategies in hybrid AC-DC microgrid operation, several key findings and discussions have emerged. The examination of hierarchical and decentralized control structures revealed a nuanced trade-off between centralized decision-making and distributed autonomy. While hierarchical control demonstrated advantages in system stability and scalability, decentralized approaches showcased resilience in the face of communication overhead and fault tolerance challenges. Optimization-based techniques, including model predictive control and evolutionary algorithms, were scrutinized for their computational efficiency and adaptability to dynamic microgrid conditions. Notably, these strategies demonstrated promising results in handling fluctuating renewable energy generation patterns and varying load demands.

The investigation into communication protocols emphasized the pivotal role they play in information exchange within microgrid systems. Findings underscored the need for a judicious selection of communication protocols, whether wired, wireless, or hybrid, considering factors such as latency, reliability, and security. Real-time monitoring and sensing technologies were identified as crucial components for enhancing the accuracy of control strategies, with diverse sensor types presenting varied impacts on the robustness of microgrid operations. Furthermore, case studies illuminating successful implementations underscored the practical relevance of coordination and control strategies, offering insights into adaptability to diverse operating conditions and addressing common challenges encountered in real-world scenarios.

The integration of energy storage systems within the scope of the review highlighted a critical aspect of hybrid AC-DC microgrid operation. The findings revealed that the coordination and control strategies must be designed to seamlessly incorporate various types of energy storage systems, such as batteries and supercapacitors, to optimize system stability, response to fluctuations, and overall efficiency. Lastly, the review considered economic and environmental metrics, evaluating the economic viability and environmental impact of different coordination and control strategies. Factors such as investment costs, energy efficiency, and greenhouse gas emissions were scrutinized, providing a holistic perspective on the sustainability and feasibility of these strategies.

V. CONCLUSION

The study has highlighted the essential role of coordination and control strategies in ensuring the resilience, stability, and efficiency of these complex energy systems. Through an in-depth analysis of hierarchical and decentralized control structures, optimization-based techniques, communication protocols, real-time monitoring, case studies, energy storage integration, and economic and environmental metrics, a nuanced perspective has been gained on the strengths and challenges associated with various approaches. The findings underscore the importance of a balanced and adaptive approach to microgrid control, considering the specific requirements of each application and the dynamic nature of renewable energy resources. The comparative analysis has shed light on the trade-offs inherent in different strategies, allowing for informed decision-making in the design and implementation of hybrid AC-DC microgrid systems. It is evident that no one-size-fits-all solution exists, and the choice of coordination and control strategies should be tailored to the unique characteristics of each microgrid, taking into account factors such as system size, resource availability, and grid conditions. As the global energy landscape continues to evolve, with an increasing emphasis on sustainability and resilience, the insights provided by this review serve as a valuable guide for researchers, practitioners, and policymakers. The identified trends and challenges pave the way for future research directions, encouraging the development of innovative solutions to address the complexities of hybrid AC-DC microgrid operation. Ultimately, this comprehensive review contributes to the ongoing dialogue on smart grid technology and renewable energy integration, fostering advancements that are crucial for the transition toward a more sustainable and reliable energy future.

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