Advancements and Future Perspectives in Hybrid Ac/Dc Power Systems: A Comprehensive Review

Keshari Nandan[1], varsha Mehar[2]
[1]MTech Scholar, [2]Assistant Professor
[1]Department of ElectricalEngineering, Bhabha College of Engineering, Bhopal, India
[2]Department of Electrical Engineering, Bhabha College of Engineering, Bhopal, India
kesharivaio@gmail.com [1] varshamehar86@gmail.com[2]

Abstract- ***This comprehensive review synthesizes the contributions and findings from various studies focused on hybrid AC/DC systems, highlighting the inherent challenges and potential future avenues for exploration. Recent advancements include the introduction of sophisticated models and Harmonic Power Flow (HPF) techniques, designed to facilitate efficient and accurate power flow evaluations while considering harmonic interactions. These models are paramount in the analysis of systems incorporating Voltage Source Converter (VSC) High Voltage Direct Current (HVDC) transmission lines, offering versatility in both primary and harmonic power flow examinations. Additionally, novel control strategies have been proposed, focusing on ensuring precise power transmission, stabilizing voltage, and mitigating harmonic disruptions. Innovative designs for distributing photovoltaic (PV) distributed generations (DGs) within hybrid AC-DC setups have also been introduced, alongside methodologies for analyzing the stability of comprehensive hybrid AC/DC power systems. The review underscores the need for advanced control strategies, real-world testing, improved harmonic mitigation techniques, standardization, integration of energy storage solutions, system security enhancements, and supportive economic and policy frameworks to foster the development and implementation of efficient, reliable, and sustainable hybrid AC/DC systems. Future research should pivot towards addressing these identified challenges and opportunities, thereby advancing the knowledge and technology associated with hybrid AC/DC power systems.***

Keywords: ***Hybrid AC/DC Systems, Voltage Source Converter (VSC), High Voltage Direct Current (HVDC), Harmonic Power Flow (HPF), Power Flow Evaluation.***

I. INTRODUCTION

In an era of rapidly evolving energy landscapes, the integration of renewable energy sources, the proliferation of high-power electronic devices, and the increasing demand for efficient and reliable electrical power, the management of electrical grids has become a complex and dynamic challenge. To meet these challenges head-on, power systems engineers have turned to innovative solutions, one of which is the Adaptive Harmonic Power Flow Algorithm for hybrid AC/DC transmission systems. Electricity is the lifeblood of modern society, powering homes, industries, and institutions. [1] Traditionally, alternating current (AC) has been the dominant means of transmitting and distributing electrical energy due to its relative ease of generation, transformation, and distribution. However, the emergence of direct current (DC) transmission technologies has brought about a paradigm shift in the way we design and operate power grids. Hybrid AC/DC transmission systems represent a pivotal advancement in grid infrastructure, offering improved controllability, enhanced efficiency, and the ability to seamlessly integrate renewable energy sources. The Adaptive Harmonic Power Flow Algorithm emerges as a potent tool to address these complexities. Harmonics, which are frequency components that deviate from the fundamental AC frequency (typically 50 or 60 Hz), have gained prominence in the context of modern power systems.

II. Literature Review

Li et al. [1] introduced a model particularly suitable for systems integrating voltage source converter (VSC) high-voltage direct current (HVDC) transmission lines. This multifaceted nonlinear model is versatile enough to be utilized in both primary and harmonic power flow examinations, especially at the convergence points. In order to validate the efficacy of their hybrid power flow method for intertwined AC/DC systems, a redesigned version of the IEEE 30-bus test system, which employs pulse width modulation (PWM)-controlled bi-terminal VSC-HVDC, serves as the experimental platform. Both simulations and detailed computations affirm that this newly proposed method outperforms conventional strategies in terms of efficiency.

Becker et al. [2] introduced a Harmonic Power Flow (HPF) technique designed to accurately depict AC power flows, taking into account the interplay among various harmonics. The conceptual foundation of the HPF approach is based on the discrepancies in the nodal equations linking the grid to resource models, and it's further resolved using the Newton Raphson technique. The current study takes the HPF approach a step further by incorporating models of hybrid AC/DC networks that interface through NICs. This adaptation ensures that harmonics either emerging from or traveling through the DC subsystems are duly represented. Consequently, the NICs' modeling and the inherent interaction between the AC and DC subsystems are integrated into the discrepancy equations and the Jacobian matrix. When applied to a representative hybrid AC/DC network, the refined HPF technique's precision is corroborated through exhaustive time-domain assessments using Simulink.

Lekić et al.[3] explored the analysis of systems using voltage source converter (VSC) high-voltage DC when varying VSC controls are implemented. The outcome of this power flow evaluation serves as a foundation for initializing the power converters.

Wang et al [4] introduced a technique where a harmonic signal is channeled into the IC using converters tied to a distributed generation linked to an AC bus. Through the use of a filter and a phase-locked-loop (PLL), the IC can pinpoint the AC bus voltage based on the signal's designated frequency. Subsequently, the IC is able to gauge line impedance using local data and counteract voltage drops, ensuring precise power transmission. Notably, this method is executed without the need for communication. When multiple ICs operate concurrently, this approach is easily adaptable, ensuring precise interplay between subgrids and equitable distribution of power across ICs, based on their stipulated capacities. Simulations and real-time tests validate the effectiveness of this approach.

Patel et al.[5] introduced a design for distributing photovoltaic (PV) distributed generations (DGs) within hybrid AC-DC setups. There's an observed average power loss enhancement of about 7.5% relative to previously reported outcomes. Additionally, there's nearly a 10% boost in the converter power factor and a significant 50% cutback in the ripple factor.

Sakinci et al.[6] introduced a methodology for analyzing the stability of comprehensive hybrid AC/DC power systems. This method distinctly considers the influences of both AC and DC systems without resorting to typical oversimplified assumptions. The AC system's portrayal is achieved through a transformation from three-phase ABC variables to a singular frame, ensuring a detailed representation of components like cables and overhead lines without compromising the intricacy of the model. This approach is elucidated further by showcasing models for passive network elements and the modular multilevel converter (MMC). The practicality of this method is highlighted using a point-to-point High-Voltage Direct Current (HVDC) link as an example.

Ortiz et al.[7] introduced a microgrid (MG) model that encompasses both DC and AC buses, integrating diverse load types and distributed generation across two voltage tiers. They utilized the MATLAB/Simulink platform to simulate the entirety of this MG. The outlined electrical framework is intended to serve as a foundational reference for subsequent research areas like reactive power offset, stability evaluations, inertia scrutiny, reliability checks, demand reaction explorations, layered control mechanisms, fault-resilient control measures, optimization techniques, and energy storage methodologies.

Ilyushin et al.[8] emphasized the importance of averting potential mishaps. They stress that the control techniques used should guarantee not only a dependable power source for consumers and power quality within microgrids but also the trustworthiness of external distribution systems they are part of. Their study offers a comprehensive review of control strategies for low-voltage AC and hybrid AC-DC microgrids, positioning them as effective solutions to these challenges..

Mehdi et al.[9] conducted an evaluation of various adaptive auto-reclosing schemes, detailing their strengths and limitations. The study concludes with suggestions for enhancing these schemes in their respective domains.

Krishnanunni et al.[10] introduced a decentralized approach to power sharing, aiming to bypass the necessity for communication among distributed generators (DGs) or microgrids. The interconnection converter, which utilizes a PI controller in the ds reference frame, works in tandem with coordinated control logic to manage power flow. However, issues arose when a nonlinear load was added, revealing significant harmonic disruptions in the current waveform. Under certain load scenarios where the grid's power dropped significantly, it was deemed unsuitable to introduce the nonlinear load. To address this, an active filter was designed and integrated to bolster system reliability. For this enhancement, a hysteresis control within the dq frame was employed. The efficacy of the recommended power control method, both with and without the active shunt filter, was substantiated using the PSCAD/EMTDC software platform across varied operational circumstances. Jasim et al. [11] introduced, characterized by its ability to neutralize harmonics while achieving pronounced gain at the grid frequency. The controller is recognized for its rapid signal tracking, adaptability to grid frequency shifts, straightforward design, and absence of steady-state discrepancies. The study further delves into a frequency-domain analysis of the PR controller. The presented methodology refines voltage and augments both steady-state and transient reactions. The cooperative control approach was tested on an IEEE 14-bus microgrid (MG) incorporating distributed communication. The results highlight the controller's proficiency in modulating MG voltage to yield a more consistent voltage profile. The examined MG, incorporating diverse resources, offers a pertinent backdrop for evaluating power flow and quality metrics in an intelligent grid framework. The study culminates with simulation outcomes that validate the advocated approach.

Reddy et al.[12] introduced a STAF Multi-loop controller that employs tuned circuits to minimize higher-order harmonics. Concurrently, a core DBN integrated with a fuzzy controller supplies a command signal to the ac/dc converter, facilitating power transmission regulation. To further stabilize dynamic voltage and align the DC bus voltage with a reference point, the VVSC Multiloop controller employs a PWM. These proposed methodologies were simulated using the Simulink platform, resulting in a stable voltage, diminished RMSE, and reduced latency.

Wang et al.[13] analyzed the efficiency of the enhanced FBD harmonic current detection approach. Using Matlab/Simulink for simulation validation, their findings indicate that the refined control strategy facilitates bidirectional power flow while ensuring DC bus voltage stability. Impressively, it also lowers the total harmonic distortion (THD) at the point of common coupling (PCC) by 0.45% in comparison to the conventional FBD control method. These results affirm the efficacy and practicality of the proposed design.

Ahrabi et al.[14] developed a detailed model of their system and carried out stability evaluations. The process of designing control parameters is exhaustively elucidated, with an emphasis on ensuring optimal stability. They determined the peak current capacity of the VSCs concerning expected harmonic orders and addressed reactive power compensation. The proposed control strategy's functionality is then scrutinized under various operational scenarios. Validation of this control approach's efficacy is offered through results from MATLAB Simulink simulations and empirical testing platforms.

Huang et al.[15] introduced a rapid fault detection technique, leveraging instantaneous active power and fault variation components. This approach aims to counteract commutation failures, address reactive power compensation issues, and tackle the dead zone challenge. Building on this foundation, they presented a differential protection algorithm rooted in integration principles to bolster system reliability. To ensure the method's effectiveness, simulations were performed on an authentic hybrid AC/DC system located in North China, considering varied fault sites and resistances. The team further authenticated the method by analyzing real-world recorded fault data.

III. Current Challenges

Model Complexity & Validation: The models introduced are complex and multifaceted, often requiring significant computational resources and expertise to use effectively.

The validation of these models is primarily through simulations, which may not fully capture the nuances and unpredictability's of real-world systems.

- Harmonic Disruptions & Power Quality: Several studies focus on harmonic disruptions and their impacts on power flow and quality. Addressing these issues is crucial, but it also presents challenges in terms of detection, mitigation, and control.
- Control Strategies: Developing and implementing effective control strategies for managing power flow, ensuring stability, and improving efficiency are ongoing challenges. The control mechanisms need to be robust, adaptive, and reliable under various operational scenarios.
- Integration & Interoperability: Integrating various AC and DC subsystems, distributed generation sources, and converters into a coherent and efficient network requires sophisticated models and control strategies. Ensuring interoperability among these diverse components is also a significant challenge.
- System Stability & Reliability: Ensuring the stability and reliability of hybrid AC/DC systems under different load conditions and fault scenarios is a critical challenge. Rapid fault detection and mitigation techniques are essential to prevent system failures and ensure continuous power supply.

IV. Conclusion

The papers reviewed provide valuable insights into the modeling, control, and operation of hybrid AC/DC systems. While significant progress has been made, there are still many challenges to address and opportunities to explore in this rapidly evolving field. Future research and development efforts should focus on addressing the identified challenges and capitalizing on the opportunities to advance the state of the art and practice in hybrid AC/DC systems.

REFERENCES

[1] Li, Yifu, et al. "Adaptive harmonic power flow algorithm for hybrid AC/DC transmission systems." 2022 IEEE Industry Applications Society Annual Meeting (IAS). IEEE, 2022.

[2] Becker, Johanna Kristin Maria, et al. "Harmonic power-flow study of hybrid ac/dc grids with converter-interfaced distributed energy resources." 2023 IEEE Belgrade PowerTech. IEEE, 2023.

[3] Lekić, Aleksandra, Hakan Ergun, and Jef Beerten. "Initialisation of a hybrid AC/DC power system for harmonic stability analysis using a power flow formulation." High Voltage 5.5 (2020): 534-542.

[4] Wang, Can, Can Deng, and Xuewei Pan. "Line impedance compensation control strategy for multiple interlinking converters in hybrid AC/DC microgrid." IET Generation, Transmission & Distribution 17.6 (2023): 1272-1286.

[5] Patel, Chintan, Tanmoy Malakar, and S. Sreejith. "Assessment of Converter Performance in Hybrid AC-DC Power System under Optimal Power Flow with Minimum Number of DC Link Control Variables." Energies 16.15 (2023): 5800.

[6] Sakinci, Özgür Can, Aleksandra Lekić, and Jef Beerten. "Generalized impedance-based AC/DC power system modeling for harmonic stability analysis." International Journal of Electrical Power & Energy Systems 143 (2022): 108456.

[7] Ortiz, Leony, et al. "Hybrid AC/DC microgrid test system simulation: grid-connected mode." Heliyon 5.12 (2019).

[8] Ilyushin, Pavel, et al. "State-of-the-Art Literature Review of Power Flow Control Methods for Low-Voltage AC and AC-DC Microgrids." Energies 16.7 (2023): 3153.

[9] Mehdi, Arif, et al. "A comprehensive review of auto-reclosing schemes in AC, DC, and hybrid (AC/DC) transmission lines." IEEE Access 9 (2021): 74325-74342.

[10] Krishnanunni, S., and Daru Anna Thomas. "AC-DC Hybrid Microgrid with Harmonic Elimination." energy sources 3: 4.

[11] Jasim, Ali M., et al. "A novel cooperative control technique for hybrid AC/DC smart microgrid converters." IEEE Access 11 (2023): 2164-2181.

[12] Wang, Guishuo, Xiaoli Wang, and Jiechao Lv. "An improved harmonic suppression control strategy for the hybrid microgrid bidirectional AC/DC converter." IEEE Access 8 (2020): 220422-220436.

[13] Reddy, P. Yanna, and Lalit Chandra Saikia. "Hybrid AC/DC control techniques with improved harmonic conditions using DBN based fuzzy controller and compensator modules." Systems Science & Control Engineering 11.1 (2023): 2188406.

[14] Ahrabi, Rouzbeh Reza, Li Ding, and Yunwei Li. "Harmonics and Reactive Power Compensation of the LCC in a Parallel LCC-VSCs Configuration for a Hybrid AC/DC Network." IEEE Transactions on Energy Conversion 37.4 (2022): 2913-2925.

[15] Huang, Jiakai, et al. "Instantaneous active power integral differential protection for hybrid AC/DC transmission systems based on fault variation component." IEEE Transactions on Power Delivery 35.6 (2020): 2791-2799.