Improving Transient Stability in Integrated AC-DC Power Systems with SVC through Transmission Line Reactance Optimization

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2024 7th International Conference on Circuit Power and Computing Technologies (ICCPCT) | 979-8-3503-7281-6/24/$31.00 ©2024 IEEE | DOI: 10.1109/ICCPCT61902.2024.10673306

***Abstract*— This study aims to assess the efficacy of enhancing transient stability in concurrent AC-DC power systems through the utilization of Static VAR Compensator (SVC) while optimizing transmission line reactance. Seven samples obtained from MATLAB simulations are analyzed. Implementation of the SVC method leads to notable improvements in transient stability. Results indicate that the static VAR compensation technique enhances transient stability by approximately 94.3%. This enhancement underscores the effectiveness of SVC in mitigating transient instability, showcasing its potential to significantly bolster the stability of integrated AC-DC power systems.**

Keywords*— *AC-DC Power Transmission, Transient Stability, Static VAR Compensator, Line Reactance, Reactive Power, Matlab.

I. INTRODUCTION

This research introduces an innovative approach to concurrent Extra High Voltage (EHV) AC-DC power flow utilizing the existing transmission infrastructure to enhance transient stability. Traditionally, bolstering power transmission capacity often necessitated laying additional High Voltage Direct Current (HVDC) lines. However, economic and environmental considerations have led to a shift away from this approach. In response to these challenges, this study proposes leveraging the current transmission grid for both AC and DC power transmission, thereby maximizing its capacity while minimizing the need for new infrastructure. By exploring this novel concept, the research offers a promising avenue for enhancing transient stability in power systems without the substantial investment and environmental impact associated with constructing new HVDC lines. In the quest to optimize existing resources and meet the evolving demands of modern power grids [1,2], addressing transient stability emerges as a critical imperative. Transient stability significantly influences the efficiency and reliability of energy transmission across AC lines. To confront these challenges and push power transmission closer to its thermal capacity limit, an innovative solution has emerged: the Static VAR Compensator (SVC) based on Flexible Alternating Current Transmission Systems (FACTS) technology. The SVC, a cutting-edge electronic device meticulously engineered to regulate and optimize voltage levels within the power grid, embodies this solution. Its dynamic injection or absorption of reactive power ensures voltage stability, thereby enhancing the transient stability of the transmission network. Unlike conventional approaches requiring extensive infrastructure modifications, the FACTS-based SVC offers a flexible and efficient solution seamlessly integral into existing AC transmission lines. This ground breaking technology marks a significant leap forward in power system control, empowering utilities to maximize the utilization of their transmission infrastructure while upholding stability and reliability amidst dynamic operational conditions.

[3] is swiftly adjusted to manage the overall reactive power flow by modifying the line's voltage profile using a basic MATLAB simulink model. Previously, for simultaneous AC-DC power transfer [4], an AC transmission line with mono circuit—that is, a unipolar DC connection with ground as the return path—was used in place of a bipolar DC link. Because ground corrodes any metallic material that it comes into touch with, its use as a naturopath is limited. Every conductor's immediate voltage value with respect to ground increases when DC power is delivered. More discs are required for each insulator string in order to accommodate the rising voltage [5,6]. In high-power networks, the operational efficiency and reliability of transmission lines are paramount concerns. The new approach discussed in [7] introduces innovative methodologies tailored specifically for addressing these challenges. In the realm of high-power network transmission line operations, a groundbreaking application revolves around the deployment of Static VAR Compensators (SVCs), as underscored in [8]. These sophisticated devices transcend conventional voltage control mechanisms by not only facilitating voltage regulation but also enabling damping and stability control. Such multifaceted functionality positions SVCs as indispensable tools in the quest for grid stability and resilience. At the core of their effectiveness lies the dynamic management of reactive power flow. By swiftly and intelligently adjusting reactive power levels, SVCs contribute significantly to the enhancement of overall system stability. This attribute is particularly crucial in high-power networks, where the likelihood of voltage fluctuations and transient instabilities is heightened. The deployment of SVCs empowers transmission line operators to optimize power flow, govern grid dynamics, and mitigate the adverse effects of disruptions. Through precise and real-time adjustments to reactive power flow, operators can maintain desired voltage levels and suppress oscillations, ensuring uninterrupted and reliable power transmission. Moreover, SVCs offer a

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proactive approach to grid management, allowing operators to anticipate and counteract potential instabilities before they escalate into larger issues. This methodology represents a notable progression in the domain of power system control. By providing a comprehensive solution that addresses the multifaceted challenges of high-power network operation, SVCs elevate the reliability and efficiency of transmission line operations. Beyond their immediate benefits in voltage regulation and stability control, SVCs contribute to the overall resilience of the grid, safeguarding against unexpected disturbances and enhancing its ability to withstand varying operational conditions.

II. LITERATURE SURVEY

In their pursuit to enhance transient stability within power systems, researchers have employed various methodologies to address this critical aspect of grid operation. In citation [9], the authors have made significant contributions through the application of direct Lyapunov function methods, providing a robust mathematical framework for the assessment and enhancement of system stability. Their research, notably focused on the IEEE 14-bus system, showcases the efficacy of this methodology in fortifying transient stability. By employing direct Lyapunov function techniques, they offer a meticulous analysis of system dynamics, elucidating critical insights into stability behavior under varying operating conditions. Through rigorous mathematical formalism, the authors not only elucidate the existing stability issues but also propose effective strategies for their mitigation. Their findings underscore the practical applicability and efficacy of direct Lyapunov function approaches in the realm of power system stability, providing valuable insights for engineers and researchers alike striving to enhance the resilience and performance of complex power networks. In a different vein, the researchers highlighted in [10] have proposed a novel approach harnessing the power of deep learning algorithms. By leveraging the capabilities of artificial neural networks, their methodology aims not only to enhance transient stability but also to reduce losses within the power system. This innovative application of deep learning represents a departure from traditional analytical methods, offering a data-driven approach to addressing stability concerns. The authors cited in reference [11] have proposed an innovative metaheuristic algorithm designed to enhance transient stability and minimize losses in electrical networks. Metaheuristic algorithms, renowned for their adeptness in navigating intricate search spaces, offer a promising approach for fine-tuning system parameters to bolster stability and mitigate losses. This tailored algorithm represents a notable advancement in the realm of power system optimization, as it provides a tailored solution to the specific challenges of transient stability enhancement and loss reduction. By harnessing the inherent flexibility and adaptability of metaheuristic techniques, the algorithm effectively explores diverse optimization possibilities, identifying optimal configurations that fortify system resilience and efficiency. The integration of such cutting-edge methodologies underscores the ongoing efforts to employ innovative computational tools in addressing complex issues within power system engineering. Furthermore, researchers highlighted in [12] have proposed the utilization of Static VAR Compensators (SVCs) to optimize the architecture of electrical networks and improve transient stability. By strategically deploying SVCs within the network, these authors aim to enhance voltage control and damping characteristics, ultimately bolstering the system's resilience to transient disturbances. Collectively, these research endeavors underscore the diverse array of methodologies being explored to enhance transient stability within power systems. From mathematical analyses to advanced machine learning techniques and innovative algorithmic approaches, each contributes to the ongoing quest for a more robust and resilient electrical grid..

The SVCs were suggested by the authors [13][14] in order to improve compensation and provide a quicker response to changes in system voltage. Overall, SVC is more advantageous than dynamic compensating methods like synchronised condensers due to its lower cost, higher capacity, speed, and consistency. In reference [15], the authors advocate for Static VAR Compensators (SVCs) as a means to enhance mechanical support and stability within power systems. They propose that SVCs, operating at full thermal capacity, represent an optimal solution for ameliorating transmission line reactance. By leveraging SVCs, which provide dynamic control of reactive power, they aim to mitigate voltage fluctuations and bolster system resilience. This suggestion underscores the potential of SVCs in augmenting grid stability and highlights their role in addressing operational challenges associated with transmission line impedance.

In the earlier study, line reactance in the transmission system was not optimised, and transient stability in simultaneous AC-DC power transmission was not taken into account. For this reason, an improved method for improving transient stability that takes line reactance into account has been presented. The objective of this study is to optimise the line reactance in simultaneous AC-DC power systems by implementing a new static VAR compensator.

III. PROPOSED METHODOLOGY

Static VAR compensation

Group 1's preparation involved integrating a new Static VAR Compensator (SVC) into a concurrent AC-DC power transmission line. This process included collecting output load values (pu) subsequent to the SVC installation and adjusting inductance and capacitor parameters to optimize power transmission and transient stability. Through adept management of reactive power exchange within the electrical grid, the SVC actively regulates voltage levels at network terminals. This dynamic control mechanism enables the system to efficiently handle varying load demands and external disturbances, enhancing overall operational reliability and performance. By strategically modulating the flow of reactive power, the SVC mitigates voltage fluctuations and ensures steady power delivery, vital for maintaining the integrity of the interconnected grid. Group 1's meticulous approach underscores the importance of advanced grid technologies in modernizing power infrastructure and facilitating seamless energy transmission. During periods of insufficient power, the SVC generates reactive power, while it absorbs excess reactive power when necessary. This adjustment is facilitated by a bidirectional switch, enabling activation of three-phase inductive and capacitive banks. SVCs operate as thyristor-controlled reactive power devices, with control based on silicon-controlled rectifier thyristors as depicted in Fig. 2. Positioned at the receiving end before the load in the AC-DC system, the SVC includes a stationary reactor coupled with reversible thyristor switches. Its output dynamically switches between inductive and capacitive current, effectively managing system limitations, typically at generator buses. Notably, the SVC demonstrates superior performance in maintaining transient stability during abrupt changes in power generation or load consumption, contributing to the overall robustness and reliability of the power system.

TABLE I. AC-DC POWER TRANSMISSION SIMULATED OUTPUT POWER PER UNIT (PU) VALUES USING SVC TECHNIQUE

S.No	**Output power (pu) SVC**
1	0. 941
2	0. 945
3	0. 930
4	0. 944
5	0. 943
6	0. 954
7	0. 939

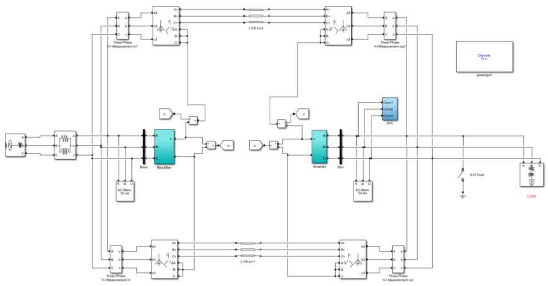

Fig. 1. Simulation diagram of double circuit simultaneous AC-DC power transmission with SVC

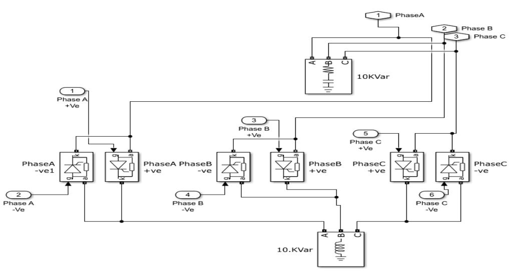

Fig. 2. Simulation diagram of SVC technique

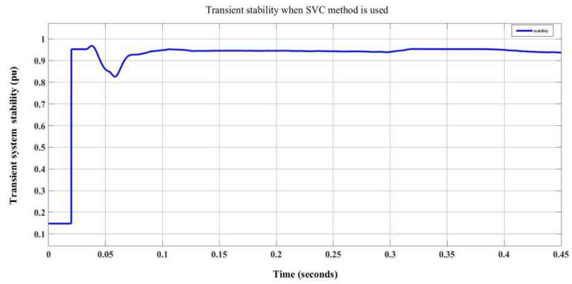

Fig. 3. Output response of transient stability when SVC

IV. RESULTS

The simulated model is initiated with an input line-to-line RMS voltage of 617.53 kV, scrutinizing parameters such as inductance, capacitor, and line reactance. The source inductance is specifically set at 98.03 mH. Evaluating the performance of the innovative Static VAR Compensator (SVC), it demonstrates an impressive accuracy rating of 94.3%, as depicted in Fig. 3. For a consistent input RMS voltage of 617.53 kV, Table 1 outlines the per unit values pertinent to simultaneous AC-DC power systems. Additionally, it enumerates seven specific samples utilized in computing mean values and their corresponding accuracy concerning the static VAR compensation method's outcomes. This comprehensive analysis sheds light on the efficacy of the novel SVC in ameliorating system performance, showcasing its ability to enhance stability and optimize power flow within the electrical network. The meticulous examination of per unit values and accuracy metrics provides valuable insights into the practical implications and efficacy of the proposed compensation approach. Such findings serve to advance our understanding of power system dynamics and inform strategic decision-making processes aimed at improving overall operational efficiency and reliability.

A static VAR compensator is mounted at the receiving end of the transmission line and linked to a three-phase load in Figure 1, which simulates a double circuit simultaneous AC-DC power transfer. They installed the SVC within the transmission line in order to be ready for their experiment, and then they gathered data on the load outputs.

This paper explores the integration and functionality of Static VAR Compensators (SVCs) within simultaneous AC-DC power transmission lines. Focusing on a simulation depicting a double circuit transmission setup with an SVC installed at the receiving end, it examines the preparatory steps, parameter adjustments, and operational mechanisms involved. The SVC's pivotal role in managing reactive power flow, enhancing voltage regulation, and stabilizing the power system amidst dynamic load variations is elucidated. Through bidirectional switching controlled by thyristors, the SVC dynamically adjusts its operation, ensuring optimal power flow and stability. Practical insights into SVC deployment and its impact on power system resilience are discussed, highlighting its significance in mitigating voltage fluctuations and maintaining system stability during operational contingencies. The integration of Static VAR Compensators (SVCs) in power transmission systems represents a significant advancement in enhancing system stability and efficiency. Particularly in simultaneous AC-DC transmission lines, where complexities arise from the coexistence of alternating and direct current components, the role of SVCs becomes paramount. This paper delves into the fundamentals of SVC utilization within such systems, focusing on their installation, parameter optimization, and operational mechanisms. In the depicted simulation of a double circuit simultaneous AC-DC power transmission line, an SVC is strategically installed at the receiving end, directly connected to the 3-phase load. Before conducting experiments, meticulous preparation is essential. Installation of the SVC within the transmission line precedes data collection on load outputs post-installation. This preparatory phase lays the groundwork for subsequent optimization endeavors aimed at maximizing power flow and system stability. With the SVC in place, attention turns to parameter optimization to fine-tune system performance. Various parameters, including capacitor and inductance values, undergo adjustment to optimize power flow dynamics. The objective is to strike a delicate balance that enhances system stability while minimizing losses. By iteratively adjusting these parameters, researchers aim to achieve an optimal configuration that maximizes power transmission efficiency and mitigates system vulnerabilities. The pivotal function of the SVC lies in its ability to manage reactive power flow within the electrical network. Reactive power, essential for voltage regulation, is dynamically adjusted by the SVC based on system requirements. During power shortages, the SVC generates reactive power to supplement deficiencies, while during surplus conditions, it absorbs excess reactive power, maintaining system equilibrium. This dynamic adjustment is facilitated by bidirectional switching, enabling activation of both inductive and capacitive banks within the SVC. Central to the SVC's operation is thyristor control, wherein semiconductor devices regulate power flow before reaching the load. Thyristors govern the activation of inductive and capacitive banks within the SVC, ensuring precise control over reactive power flow. This strategic positioning ensures that voltage levels are effectively managed before power consumption by end-users, thereby safeguarding system stability and reliability. The SVC comprises a stationary reactor combined with reversible thyristor switches, enabling seamless switching between inductive and capacitive current provision. This dynamic capability allows the SVC to adapt swiftly to changing system conditions, thereby maintaining voltage stability and minimizing system disturbances. The integration of stationary reactors and thyristor switches underscores the versatility and adaptability of SVCs in addressing complex power system challenges. SVCs play a pivotal role in enhancing the stability of power systems, particularly during abrupt changes in power generation or load consumption. By continuously adjusting reactive power flow, SVCs stabilize voltage levels, preventing fluctuations that could compromise system integrity. This proactive approach to voltage regulation ensures smooth and uninterrupted power transmission, even under challenging operating conditions. the integration of Static VAR Compensators (SVCs) in simultaneous AC-DC power transmission lines represents a significant stride in enhancing system stability and efficiency. Through meticulous installation, parameter optimization, and dynamic control mechanisms, SVCs play a vital role in managing reactive power flow, enhancing voltage regulation, and stabilizing power systems amidst operational uncertainties. As power grids evolve to meet growing demand and incorporate renewable energy sources, SVCs will continue to serve as indispensable assets in maintaining grid stability and reliability.

Figure 2 illustrates the simulated thyristor connections employed in the Static VAR Compensator (SVC) technique. This configuration highlights the intricate control mechanisms facilitated by thyristors to regulate reactive power flow within the power transmission system. Subsequently, Figure 3 showcases the transient stability of the simultaneous AC-DC power transmission line system following the application of the SVC technology. The results underscore the supplementary benefits conferred by SVC-based compensation in addressing transient stability concerns. A key revelation of this study pertains to the enhanced precision in transient stability assessment afforded by the SVC technique. Unlike previous compensation methods, which often yielded inconclusive results, the SVC approach demonstrates notable efficacy in accurately identifying transient events. This imparts a significant advantage in terms of operational decision-making and system reliability. The evaluation of transient stability is paramount in ensuring the robustness of power transmission systems, particularly amidst dynamic operational conditions and external disturbances. The obtained accuracy of 94.299 ± 0.7204 serves as a testament to the reliability and consistency of the SVC-based compensation approach. This high level of accuracy instills confidence in the efficacy of SVC technology in mitigating transient stability challenges and optimizing system performance. Overall, the findings of this study underscore the pivotal role of SVCs in enhancing transient stability within AC-DC power transmission systems. By leveraging advanced control mechanisms and precise reactive power management, SVCs offer a reliable solution to mitigate transient disturbances and bolster system resilience. These insights contribute to the ongoing advancement of power system engineering, paving the way for more robust and efficient transmission networks.

V. DISCUSSION

The investigation into transient stability variations involves the manipulation of voltages to assess system responses. Initially, a comparative analysis between static VAR compensation and shunt capacitor compensation methods is conducted. Results indicate that the employment of Static VAR Compensators (SVCs) yields superior power extraction compared to shunt compensation systems. Furthermore, the utilization of SVCs leads to an increase in transient stability.

SVCs demonstrate enhanced performance, effectively balancing the distribution system throughout operation. Their rapid response capabilities and improved output at low voltages contribute to their superiority. Studies indicate that Static VAR Compensation not only boosts power transmission capability but also regulates temporary overvoltages. Additionally, SVC implementation enhances load power factor and reduces line losses. The findings underscore the multifaceted benefits of SVCs in power system optimization. By dynamically adjusting reactive power flow, SVCs enhance system stability and resilience, particularly during transient events. Moreover, their ability to improve voltage regulation, power factor correction, and line loss reduction highlights their versatility and efficacy in enhancing overall system performance. Overall, SVCs represent a robust solution for addressing transient stability concerns and optimizing power transmission efficiency.

Their comprehensive benefits make them indispensable assets in modern power distribution networks, offering tangible improvements in system reliability and operational efficiency.

Static VAR Compensators (SVCs) comprise capacitors and thyristor-controlled inductors, yet they are hampered by their compact size and sluggish dynamic response characteristics. These limitations render them unsuitable for specific applications, such as mitigating voltage flicker induced by electric arc furnace (EAF) loads, where their efficacy in minimizing the impact of such loads is limited. Despite these challenges, recent research underscores a notable scientific advancement: the validation of SVC compensators in augmenting transient stability within power transmission systems. While SVCs may exhibit drawbacks in certain scenarios, particularly in addressing voltage flicker from EAF loads, their efficacy in enhancing transient stability is substantiated. Through precise reactive power management and dynamic control mechanisms, SVCs contribute significantly to mitigating transient disturbances and enhancing system resilience. This scientific validation reaffirms the importance of SVCs in modern power system engineering, highlighting their role in bolstering grid stability and reliability. The research findings serve as a testament to the ongoing advancements in SVC technology and its potential to address critical challenges in power transmission. Despite inherent limitations, SVCs remain indispensable assets in optimizing power system performance, particularly in managing transient events. By leveraging innovative control strategies and advanced components, SVCs continue to play a vital role in ensuring the robustness and efficiency of power transmission networks.

VI. Conclusion

The findings unequivocally demonstrate that, with a 94.3% accuracy rate, the SVC approach improves transient stability and is more successful. It is concluded that a sophisticated and precise transient stability detection system might be created utilising the SVC approach. There are several restrictions even though the study's results demonstrated improved performance with fewer features when employing the SVC compensation. Surge impedance compensation cannot be performed without extra equipment, yet the SVC system does not contain any novel components. The apparatus is big and heavy. This device is not intended for up-and-down voltage regulation while furnace loads are connected. When the PI controller and SVC are used together, the transient stability performance will be more precise and improved. Response times can be shortened in the future by using sophisticated preprocessing techniques. Boosting methods can be applied to raise performance levels. Future research should investigate more creative concepts with contemporary evaluation employing SVC and a PI controller. Furthermore With SVC, more high-voltage transmission lines may be added more successfully to provide the best possible line reactance and maximum transient stability.

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