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Simulation & Analysis of Multigrid HVDC System Using Statcom Device

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Abstract: - This research paper aims to comprehensively examine combining Multigrid High Voltage Direct Current (HVDC) systems with Static Synchronous Compensators (STATCOMs) to improve power quality and system stability. Due to the growing need for effective power transmission, it is imperative to employ sophisticated technologies to address voltage fluctuations harmonic distortions, and enhance system reliability. The integration of STATCOMs in HVDC systems has demonstrated encouraging outcomes in tackling these difficulties. This paper analyses the theoretical underpinnings, operational characteristics, and benefits of integrating STATCOMs into Multigrid HVDC systems. Furthermore, the proposed system undergoes simulation studies and case analyses to assess its performance across different operating conditions and contingencies. The results emphasize the notable enhancements in voltage regulation, power factor correction, and system stability attained by the collaborative functioning of Multigrid HVDC systems with STATCOMs. The research findings significantly contribute to the knowledge and comprehension of hybrid power system configurations, providing valuable insights for the development and execution of future high-voltage direct current (HVDC) infrastructure.

Keywords: Multigrid HVDC, STATCOM, Power Quality, System Stability, Voltage Regulation, etc.

I. INTRODUCTION

The increasing need for electricity, propelled by industrialization and urbanization, requires advancing efficient and dependable strategies in power transmission. HVDC technology has become a crucial solution for transmitting large amounts of power over long distances with lower losses and improved efficiency compared to traditional AC systems. Nevertheless, it is crucial to prioritize maintaining optimal power quality and stability to guarantee the smooth operation of contemporary power grids. Power quality is a multifaceted concept encompassing essential factors, including voltage regulation, harmonic distortion, and frequency stability. These factors substantially influence the dependability and efficiency of electrical systems. Inadequate power quality results in operational inefficiencies and presents potential hazards to equipment integrity and the system's resilience. Similarly, it is essential to ensure the consistent functioning of the system to avoid voltage fluctuations, variations in frequency, and possible breakdowns in the power grid, especially in interconnected networks with different sources of power generation. HVDC is the most cost-effective method for transmitting large amounts of power over long distances. It offers flexibility in controlling power flow, asynchronous power grid interconnections, and integrating renewable energy. One of the crucial components of the HVDC system is the protection of the DC transmission line. This unit plays a significant role in ensuring rapid fault clearance and maintaining the overall operational security of the HVDC transmission system. In the contemporary era, the escalating need for power supply and enhancing transmission capabilities are crucial concerns. The HVDC transmission network is considered superior to the HVAC transmission network for long transmission systems. High Voltage Direct Current (HVDC) power transmission is increasingly appealing due to substantial advancements in power electronics technology over the last twenty years. High-voltage direct current (HVDC) transmission provides notable benefits, such as an ample rating power supply for long distances with fewer losses in transmission. However, it is essential to note that HVDC transmission-connected converters inherently consume significant quantities of reactive power. Typically, the reactive power requirements of the converter amount to approximately 50% of DC power transmitted in an HVDC system. When HVDC thyristor converters are connected with low-rating AC terminals, several significant concerns arise regarding their safe operation.

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Integrating Static Synchronous Compensators (STATCOMs) with Multigrid HVDC systems has emerged as a promising strategy for addressing these challenges. Advanced power electronics devices known as STATCOMs can rapidly inject or absorb reactive power into the grid, thereby effectively regulating voltage levels and improving the overall dynamics of the system. STATCOMs have the potential to enhance power quality and system stability by working together with Multigrid HVDC converters in a coordinated manner. The fundamental goal of this article is to comprehensively examine the theoretical foundations, operational complexities, and practical ramifications associated with the integration of STATCOMs on Multigrid HVDC systems. The paper aims to assess the efficacy of this integrated approach in improving power quality and stability under various operating conditions through simulation studies and thorough analysis. These investigations can provide valuable insights for future HVDC infrastructure design, implementation, and administration. In summary, the incorporation of STATCOMs into Multigrid HVDC systems signifies a notable progression in power transmission technology, presenting the potential for electrical grids that are more robust, effective, and environmentally friendly. This integrated approach has the potential to address the changing needs of modern energy systems and help transition to a cleaner and more reliable energy future by reducing power quality issues and improving system stability [1-2]. This paper also provides VS (voltage stability) information for the Multigrid system comprising two High Voltage Direct Current (HVDC) links that are interconnected via an Alternating Current (AC) tie-line. In a weak system, the issue of voltage instability becomes more pronounced when either one or both HVDC links terminate [3]. This paper examines a Multigrid system based on Line Commutated Converters (LCCs) and analyzes its stability under large disturbance voltages across different operating control modes. Due to the inherent consumption of reactive power by LCCs, there exists a significant likelihood of voltage instability or collapse. STATCOM (Static Synchronous Compensator) balances reactive power on AC buses. Additionally, it has been demonstrated in reference [2] that dynamic analysis yields more precise outcomes than static analysis when addressing the issue of voltage instability. The study examines the impact of the STATCOM's location, disturbance location, and different operations modes in the HVDC system with the multi-grid system.

II. CHALLENGES & OBJECTIVES

Challenges:

The dynamics of multigrid HVDC systems are inherently complex due to the interconnection of multiple grids through HVDC links. Control strategies and system stability pose challenges when coordinating the operation of STATCOMs within the complex system architecture. Voltage regulation is essential for maintaining power quality and system reliability by keeping voltage levels within acceptable limits. The presence of multiple grid interfaces and dynamic load variations in Multigrid HVDC systems makes voltage regulation more difficult. The introduction of harmonic distortions into the grid by HVDC systems has been observed to harm the performance of sensitive loads and equipment. The successful integration of STATCOMs to mitigate harmonic distortions necessitates meticulous design and coordination to attain optimal outcomes. Multigrid high-voltage direct current (HVDC) systems are prone to transient disturbances, including faults and abrupt load fluctuations, which can affect the system's stability. Ensuring the efficient and timely provision of reactive power support through coordinating STATCOMs is imperative to uphold transient stability. The attainment of smooth coordination between the control systems of STATCOMs and HVDC converters is of utmost importance to fully harness the synergistic advantages the integrated system offers. Creating resilient control algorithms that guarantee seamless communication between STATCOMs and HVDC converters poses a substantial obstacle.

Research Objectives:

This paper study aims to check the effects of integrating STATCOMs on the performance of Multigrid HVDC systems, specifically concerning power quality, voltage regulation, and system stability. This entails the execution of thorough simulation studies across diverse operational scenarios. The objective is to enhance voltage regulation, mitigate harmonic distortions, and improve transient stability in Multigrid HVDC systems by developing and optimizing control strategies for STATCOMs. The research examines various control modes and coordination schemes employed in the interaction between STATCOMs and HVDC converters. To determine how effective the integrated system is, simulation studies and comparison analyses with traditional

HVDC systems are conducted as part of the system performance evaluation process. To quantify the advantages of integrating STATCOM, essential performance metrics must be evaluated, including voltage stability, power factor correction, harmonic content, and transient response. To effectively tackle the implementation challenges related to integrating STATCOMs with Multigrid HVDC systems, it is imperative to identify and address these challenges. This entails examining various factors, including the dimensions and positioning of equipment, the communication protocols, and the real-time control implementation. This study presents design guidelines and recommendations for integrating STATCOMs with Multigrid HVDC systems, drawing upon the research findings. In practical applications, these guidelines aim to assist system designers and operators in enhancing the performance and reliability of integrated HVDC-STATCOM systems. The research paper seeks to contribute to Multigrid HVDC systems' progress by examining the associated challenges and objectives. It attempts to show how well power quality, voltage stability, and overall system performance can be enhanced by integrating STATCOM. The topic of this paper is the stability of a high-voltage direct current (HVDC) link with a static compensator (STATCOM). A weak alternating current (AC) system is connected with commutation failures and power instability stability enhancement.

In this study, a shunt controller based on the voltage source converter topology—which is typically implemented by a voltage source converter (VSC) with the ability to produce controllable current directly at its output terminal—is presented. Using MATLAB/Simulink, this shunt controller is assessed in a power transmission network, and its behavior and performance are compared with and without STATCOM in test systems. The simulation results show that the simulated shunt controller can significantly improve the system's performance.

III. HVDC SYSTEM

To conduct a research paper on the Multigrid HVDC System using STATCOM, it is essential to develop a comprehensive comprehension of the HVDC system, including its constituent elements, functioning, and importance in contemporary power transmission. Electric power's generation, transmission, and distribution occur in the form of alternating current (AC). Transmission and distribution lines carry power from the generating stations to the final consumer. Transmission lines operate at high or very high voltages and are quite long. The DC power system concludes with the inversion of DC power to AC power, synchronizing with the subsequent AC network. The complete high-voltage direct current (HVDC) system comprises three components: the transmission section, the inverter station, and the converter station. A thyristor bridge rectifier with 6, 12, or 24 pulses is part of the transmitting end, also known as the converter station, and a similar rectifier with an inverter mode makes up the receiving end, also known as the inverter station. The following is a framework for examining HVDC systems in the context of your research paper:

Overview of the HVDC System:

HVDC presents a distinct contrast to conventional HVAC (Alternating Current) systems. The benefits of HVDC transmission include reduced losses, improved efficiency over extended distances, and the ability to connect AC systems asynchronously.

Categories of HVDC Systems:

I am distinguishing point-to-point HVDC systems from multigrid HVDC systems. Elucidation of Multigrid High Voltage Direct Current (HVDC) systems and their importance in linking multiple Alternating Current (AC) grids.

Elements of HVDC Systems:

Medium of transmission: The transmission medium employed in HVDC systems, such as overhead lines and submarine cables, will now be elucidated. Factors to be taken into account when choosing the transmission medium include distance, environmental conditions, and project specifications.

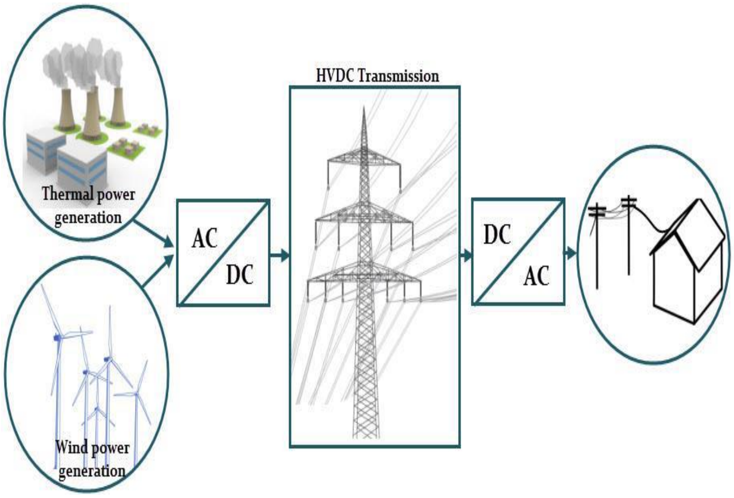

Figure- 1 HVDC System

Systems for Control and Protection: Summary of control and protection systems utilized in high-voltage direct current (HVDC) systems.

The control systems are critical in regulating power flow for the proposed work, maintaining system stability, and synchronizing the grid. The significance of protection systems lies in their ability to detect and isolate faults, thereby mitigating the risk of cascading failures.

HVDC System Operation:

Power Flow Control: Power flow control mechanisms in HVDC systems will be elucidated. Implementing converter control strategies, such as pulse-width modulation and phase angle control, facilitates the regulation of active and reactive power flow.

Control of voltage and reactive power: This paper explores various voltage control methods employed to ensure grid stability—the significance of reactive power regulation in maintaining voltage stability and system dependability.

The Capability of Fault Ride-Through: One of the most essential components in maintaining system stability in transient disruptions is the fault ride-through capability—techniques to enhance the ability of high-voltage direct current (HVDC) systems to tolerate faults.

Importance of HVDC Systems in Multigrid Applications:

Grid interconnection: In the context of interconnecting multiple AC grids with varying frequencies and voltages, the significance of Multigrid HVDC systems cannot be overstated.
The crucial use of HVDC systems in facilitating the integration of renewable energy and enhancing grid resilience.

Enhanced Power Transfer Capability: HVDC systems offer several advantages in augmenting power transfer capacity across extensive distances and facilitating the connection between remote generation sources and load centers.

Adaptability and Authority: Exploration of the adaptability and manageability provided by MG-HVDC systems, specifically in grid environments, subject to change.

Utilizing proposed MG-HVDC (Multi Grid- HVDC) systems will bolster grid stability and enable load balancing.
To offer a thorough examination of HVDC systems and establish a basis for exploring the integration of STATCOMs in Multigrid HVDC systems, it is advisable to include these sections in your research paper. Reactive compensators and HVDC systems are usually operated and controlled independently, and only steady-

state conditions are considered when analyzing their interaction. The performance of the HVDC system can be enhanced in both transient and dynamic states by improving the coordination between the reactive power compensator and the HVDC system. Efficient performance of the HVDC system during transients is crucial. The growing power demand in various industries has necessitated the integration of HVDC and AC systems. Following the advancement of FACTS controllers, transmission capability has been enhanced significantly. Implementing these controllers enhances the regulatory control and stability of power networks. The STATCOM, also called the Static Synchronous compensator, is a crucial component of Flexible AC transmission systems (FACTS) because it controls transmission line voltages, improves transient stability, and corrects reactive power fluctuations. The stability of a high-voltage direct current (HVDC) link with a static compensator (STATCOM) is the subject of this study at both ends. The main focus is the case in which the link is coupled to a weak AC system exhibiting commutation failures and power instability stability enhancement.

IV. PROPOSED SYSTEM

Model of HVDC-STATCOM

Statcom is a constituent of the FACTS family of contrivances. Figure-2 illustrates the utilization of STATCOM connected at the inverter side for high voltage direct current (DC) transmission. It demonstrates the ability to reduce sag, swell, and notches. It offers enhanced control over power flow. Furthermore, it enhances power transfer efficiency in a high-voltage transmission line [1]. Line charging and thyristor switching at the converter end typically cause specific harmonics to be generated and voltage to drop, which causes swell. It travels to the receiving end and directly affects the quality of power. The system malfunctions and performs inefficiently due to the load receiving this inferior power. In the event of voltage instability or fault, if the STATCOM device is connected at the load end. The effects of astringency and quality are reduced. Thus, enhancing the potent quality. In the contemporary context, power quality emerges as a primary concern. The Figure illustrates the provision of AC supply through an alternator while the voltage level of the rectifier converter, typically a three-phase transformer, is utilized.

Consequently, supplying power to the rectifier is called an HVAC system. The DC o/p is obtained by a rectifier and is referred to as a DC link. The direct current (DC) supply is reversed by utilizing an inverter consisting of a six-pulse arrangement of Thyristors. Once the AC output is obtained from the inverter, it is subsequently supplied to the STATCOM for mitigation.

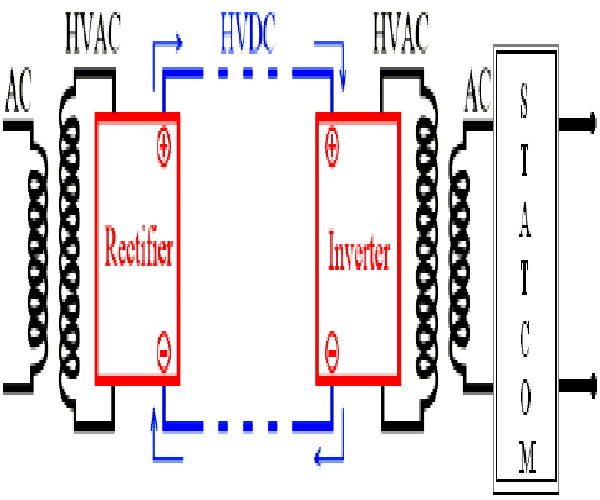

Figure-2 Connections of STATCOM with HVDC system

The load must be disconnected from the HVDC inverter before restarting the system. Pre-energized STATCOM is designed to power the high-voltage direct current (HVDC) system using a rectifier and a small generator. The auxiliary power supply will power the DC capacitor until the HVDC converter turns on. As soon as the DC capacitor is fully charged, the STATCOM output voltage is raised, which causes the transformer to energize gradually. After that, the HVDC converter can be opened up to send out active power. After the HVDC system has recovered, the disconnected switch is opened to isolate the auxiliary power supply to the DC capacitor of the STATCOM. Buffering can effectively mitigate short-term active power variation and reactive power perturbation to the main grid.

Modelling of STATCOM Device

The STATCOM device is mainly used as a contemporary tool for compensating reactive power, and it operates using voltage source converter technology. Despite being composed of power electronic circuits such as an SVC, its operational characteristics resemble an SC's. The active compensator depicted in Figure-3 is indeed a fully controllable device. A STATCOM keeps the bus voltage below preset thresholds as a regulated voltage source. The maximum current that can flow through the power electronic circuit of a STATCOM is referred to as its limit. Figure 4 shows the voltage-current (VI) characteristics of a STATCOM.

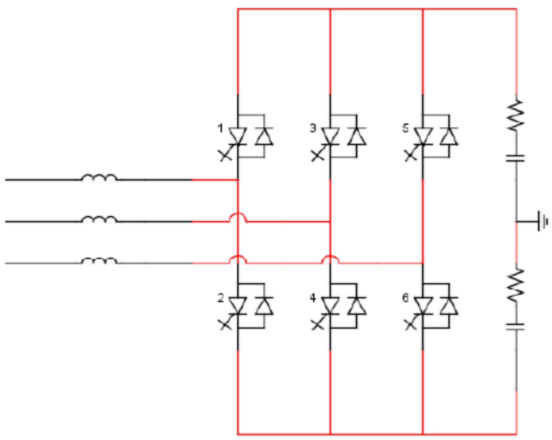

Figure-3 Connections of the STATCOM model

It is crucial to recognize that a STATCOM can continue to supply its full current even when the voltage drops to a shallow level. The reactive power output of the system is directly proportional to the bus voltage as opposed to the square of the bus voltage, as is the case with an SVC. This feature increases STATCOM's capacity to support the system voltage and improves the voltage's stability. Generally speaking, a STATCOM's control system sets a current limit, like limiting the Iq order in the DQ decoupling control. Usually, the exact mechanism is used to enforce the current steady state and transient state constraints. The difference between the limits of the steady state and transient states' limits would not be very significant, even though they could be designed in a way that allows for a brief increase in current under specific circumstances.

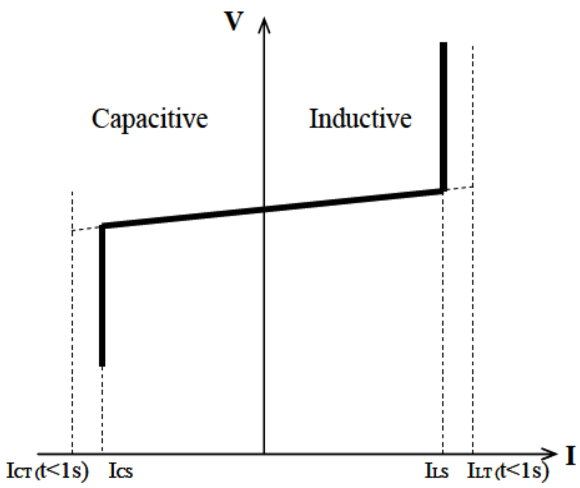

Figure-4 Operation V-I Characteristic of STATCOM

Advantages and Improvements in Power System Efficiency through HVDC and FACTs

As a result of a significant increase in power consumption in heavily populated regions, vast quantities of power need to be conveyed to major power centers using overhead lines and cables. To optimize transmission losses, it is necessary to employ higher voltage levels. Employing power electronic devices, like FACTS and HVDC, provides the necessary control functionality to maximize the power system. Several factors, such as the load-dependent phase shift experienced along the transmission line, the voltage drop experienced by the line, and the thermal limitations of its conductors, limit the power transmission capability in HVAC applications. A critical component in limiting power transfer in long overhead lines is the Surge Impedance Loading (SIL). The transmission line can carry reactive and active power during regular operation if it stays within a predefined voltage tolerance range, typically set at ±5%.

V. SIMULATION & RESULTS ANALYSIS

HVDC-STATCOM System Proposal

In this configuration, the rectifier and the inverter are interconnected in series as gate-pulse-based IGBT converters. Figure-5 illustrates the interconnection of the converters via a 75-kilometer line and smoothing reactors. The Three Phase Transformer (Three-Winding) blocks are used to model the converter transformers, which can be categorized as Wye grounded/Wye/Delta. Fig-5 below shows STATCOM modelling with the HVDC system for power quality improvement.

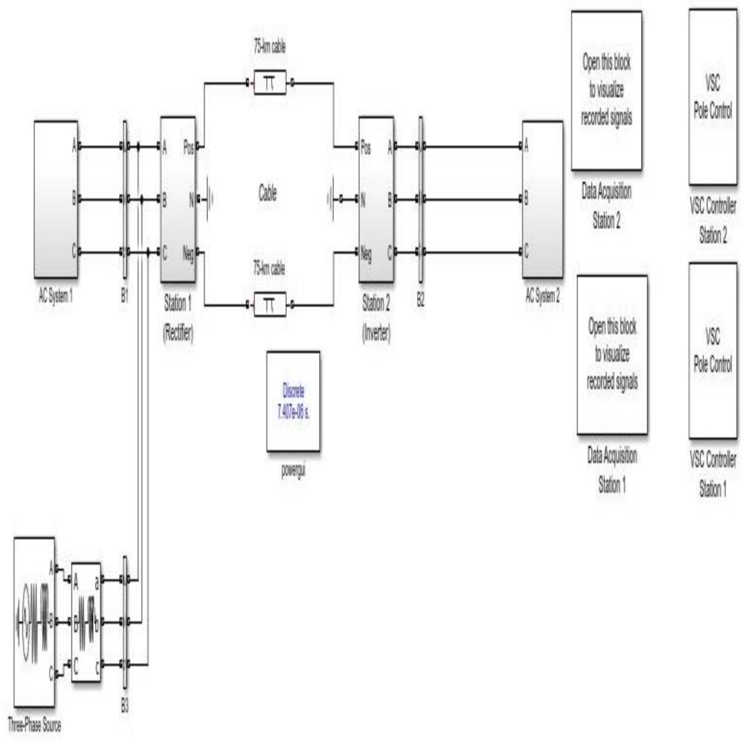

Figure 5- Matlab Model of MG-HVDC system without STATCOM

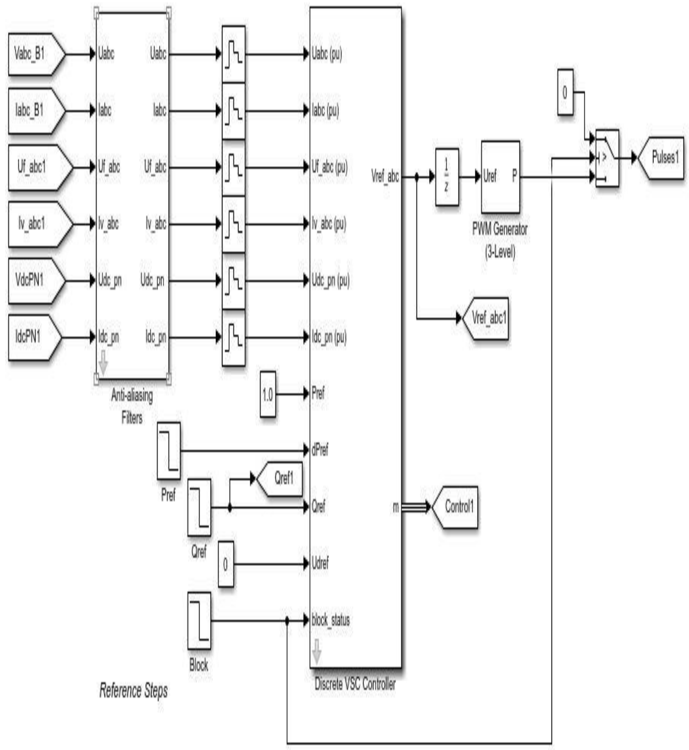

Fig 6- VSC controlling subsystem

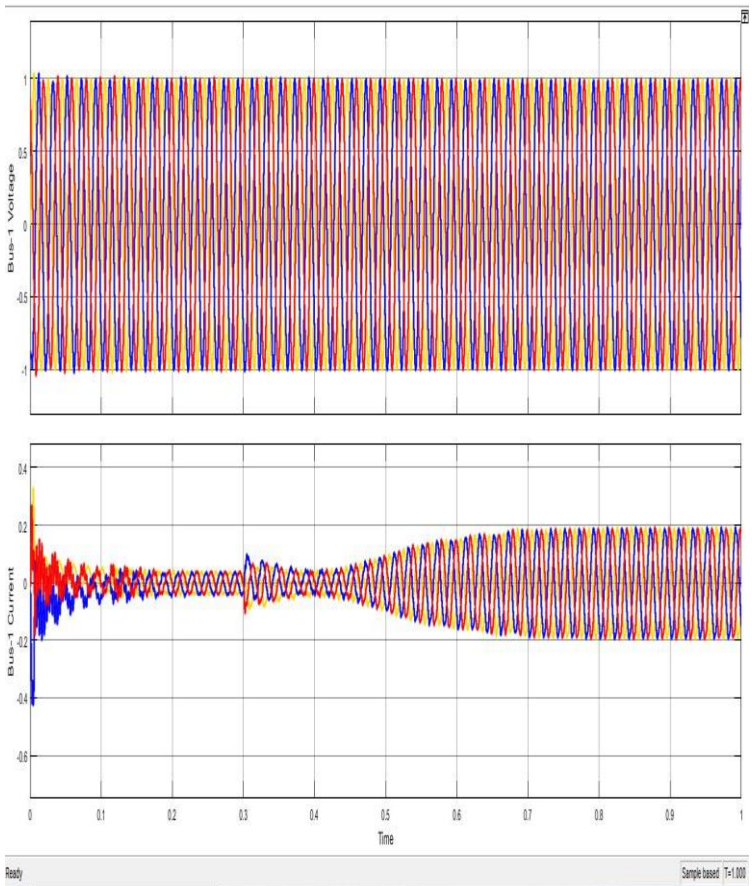

Fig 7- Simulation waveform at Bus-1 without STATCOM

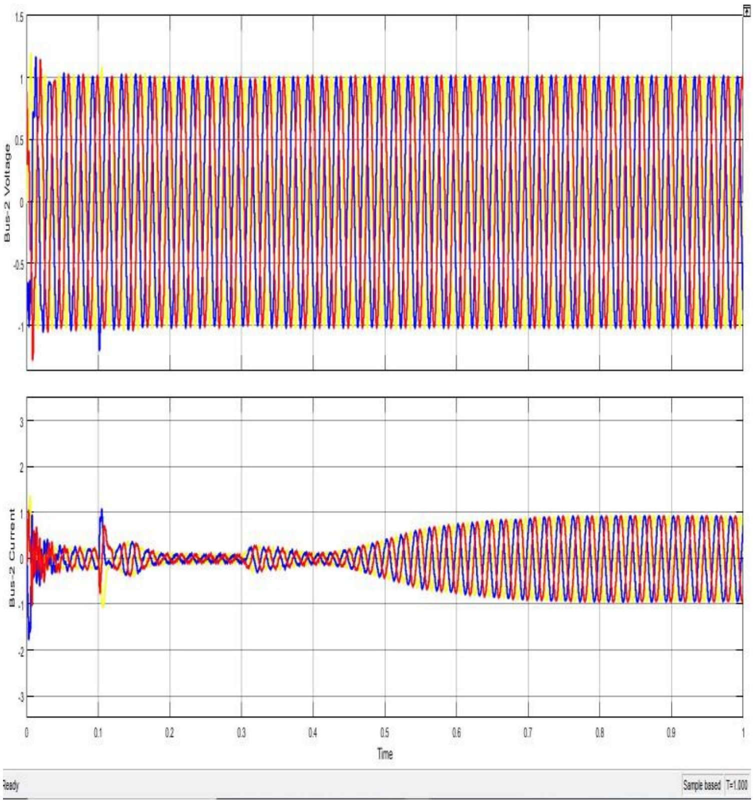

Fig 8- Simulation waveform at Bus-2 without STATCOM

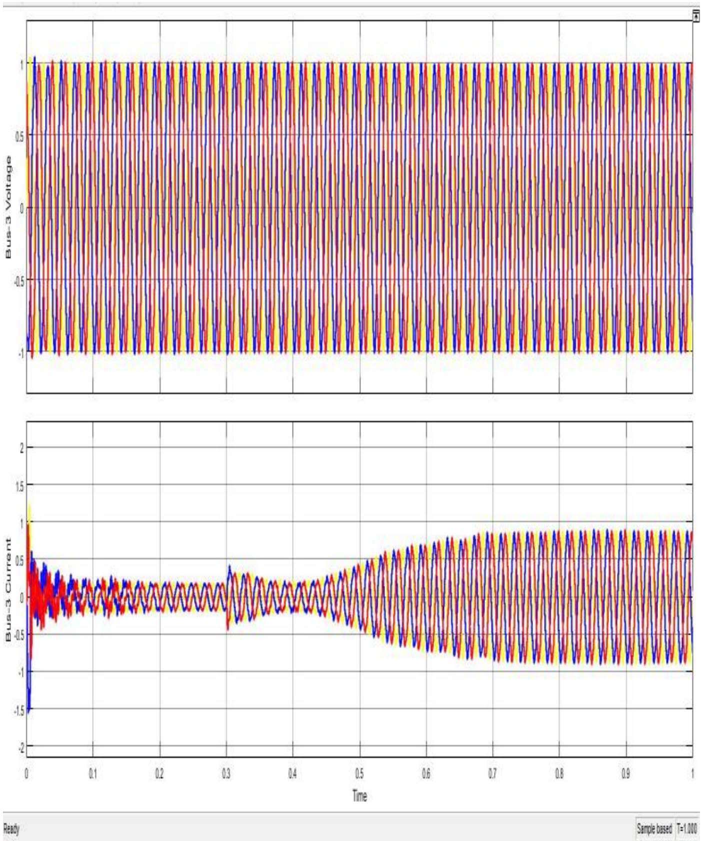

Fig 9- Simulation waveform at Bus-3 without STATCOM

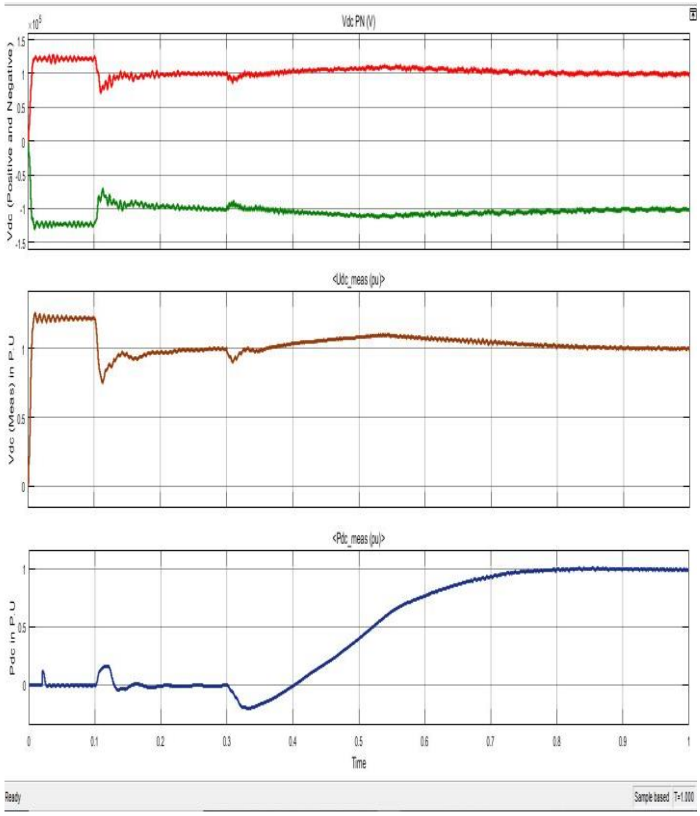

Fig 10- Simulation outcome at converter-1 side

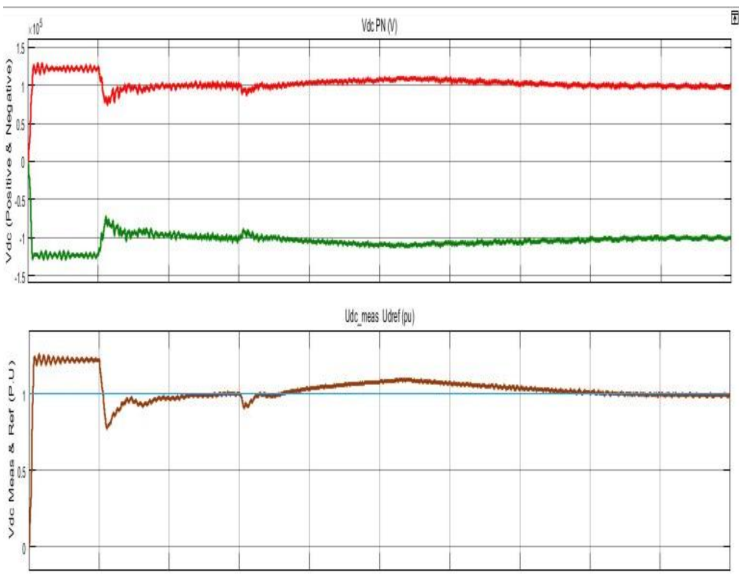

Fig 11- Simulation outcome at converter-2 side

A pulse generator is used in series as part of the firing-angle control system configuration, and one of the generators serves as a modified HVDC bridge. HVDC power converters with thyristor valves will be assembled using a converter bridge with a twelve-pulse configuration. This is accomplished by utilizing star-star and star-delta connections. There is also research to look into minimizing harmonic effects.

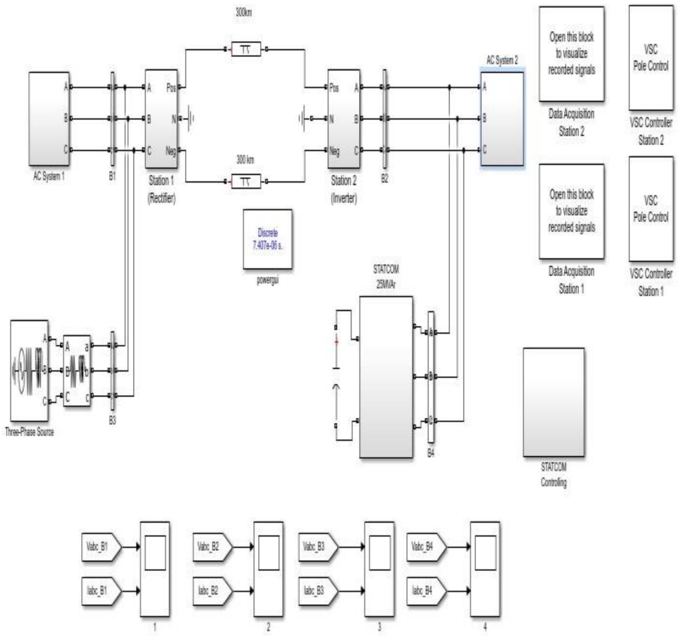

Fig 12- Matlab Model of MG-HVDC system with STATCOM integration

The MATLAB/SIMULINK program is the simulation tool used in this investigation. To aid in voltage control, the firing angles are continuously kept at a minimal or nearly constant level. Three-level IGBT bridges are thought to be the best way to control direct current (DC) voltage. Because of the high harmonic content, using additional bridges or converters in series is not advised. There are two ways to control power: voltage control and current control. It is essential to maintain a constant voltage in the DC link to reduce power loss and only adjust the current when necessary. The rectifier station is in charge of controlling the current, and the inverter is in charge of controlling the direct current (DC) voltage. The firing angle at the rectifier station and the extinction angle at the inverter station are adjusted to study the functionality and properties of the HVDC system. The voltage and current waveforms are shown in the figure. In an HVDC network system, the output is obtained via the STATCOM.

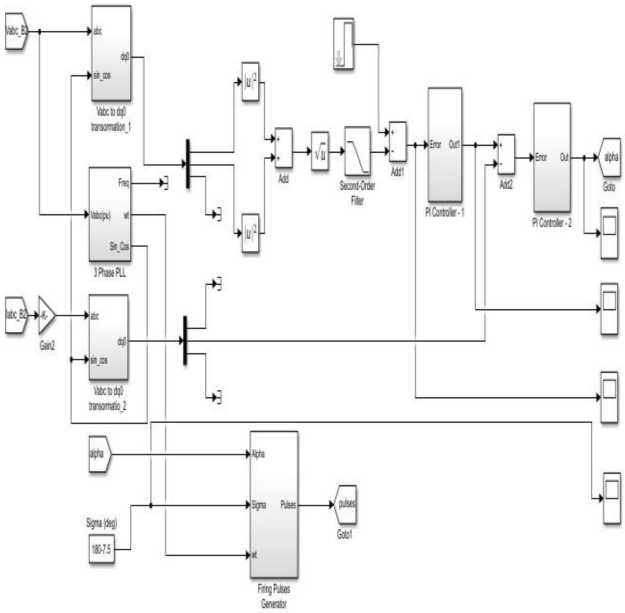

Fig 13- STATCOM controlling subsystem

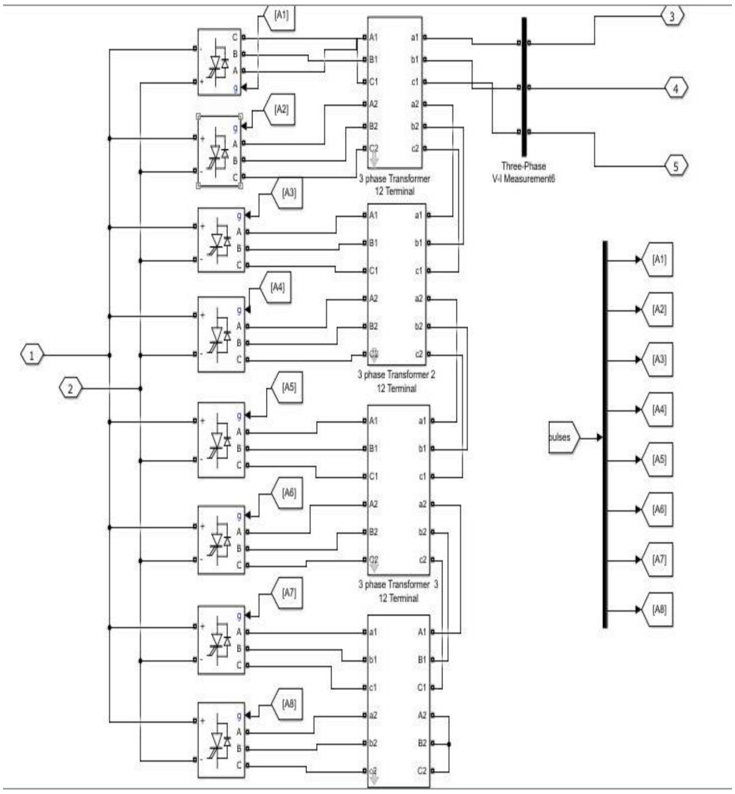

Fig 14- VSC converter STATCOM subsystem

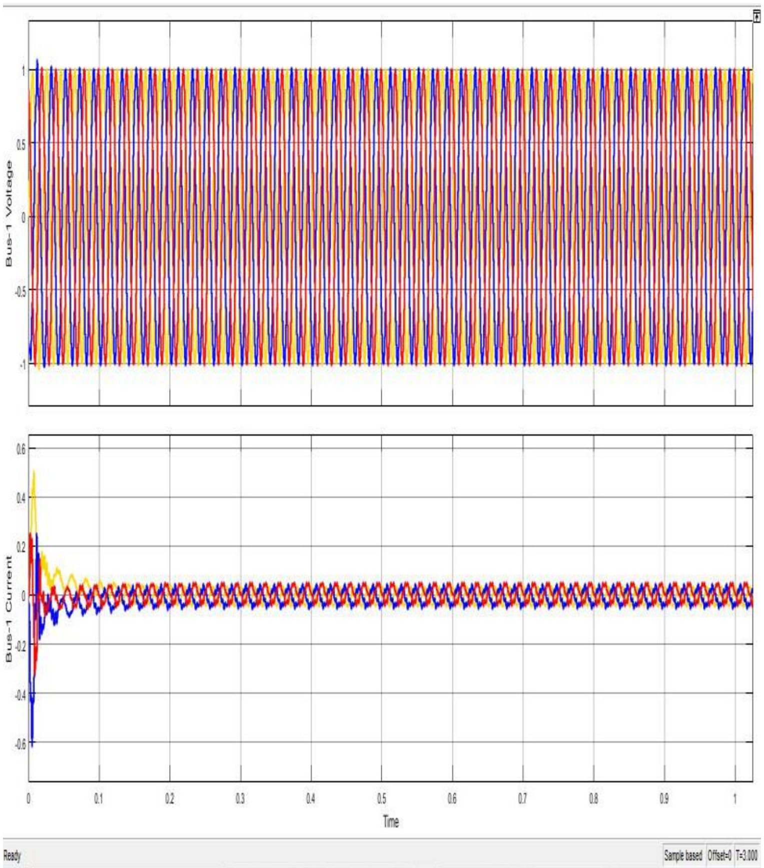

Fig 15- Simulation waveform at Bus-1 with STATCOM controlling

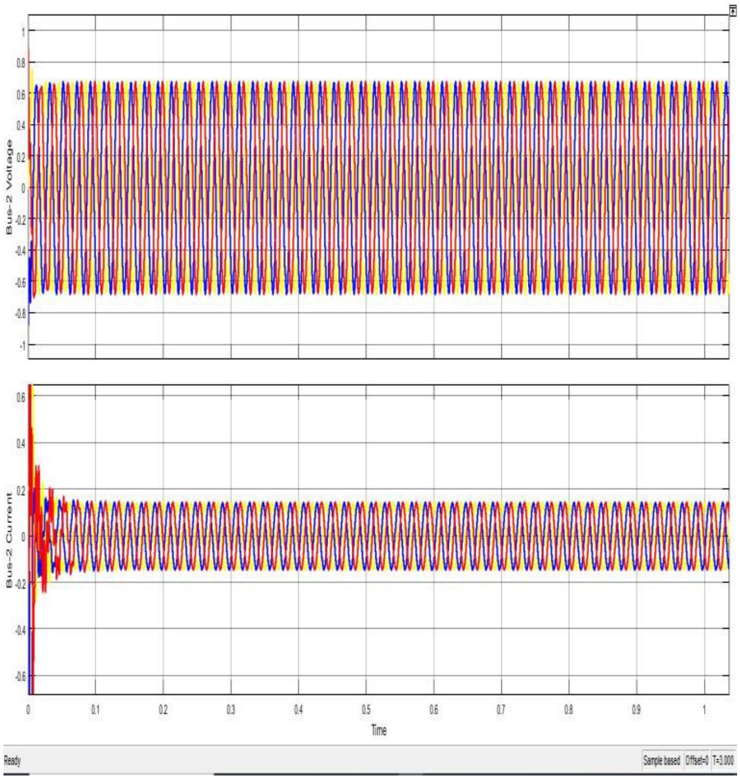

Fig 16- Simulation waveform at Bus-1 with STATCOM

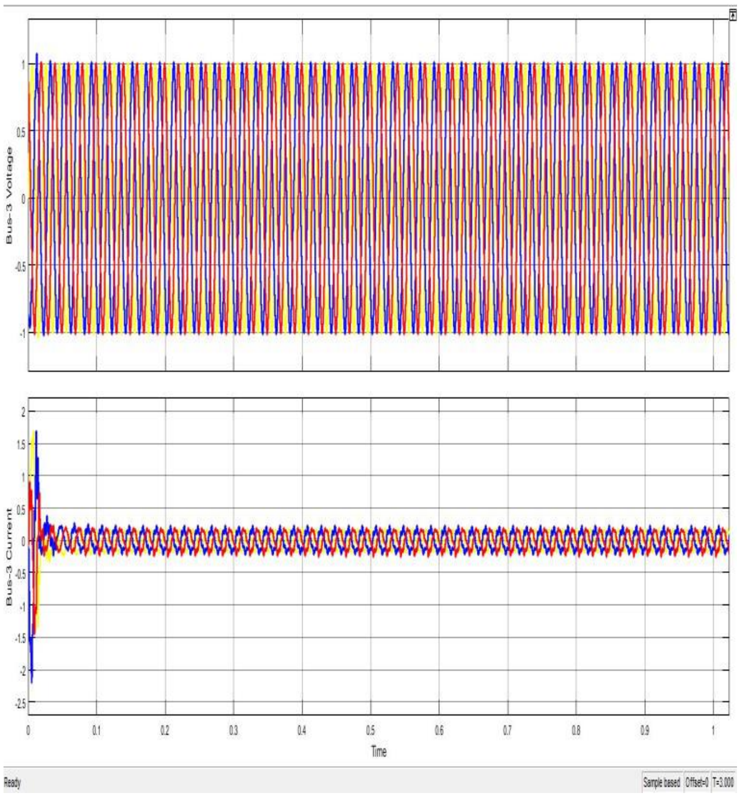

Fig 17- Simulation waveform at Bus-1 with STATCOM

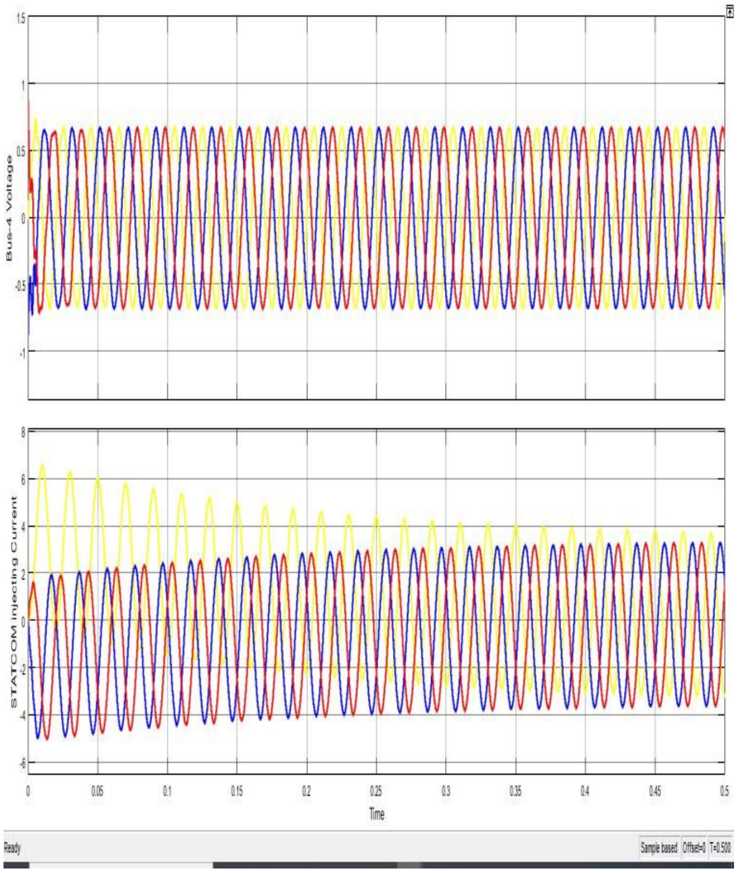

Fig 18- Simulation waveform at Bus-4 with STATCOM

VI. CONCLUSION

The present study has investigated the incorporation of Static Synchronous Compensators (STATCOMs) into MG-HVDC systems and the resulting consequences for power transmission infrastructure. The efficacy of integrating STATCOM in Multigrid HVDC environments has been proven through extensive simulation studies and analysis, resulting in improved power quality, voltage stability, and system reliability. This paper proposes a STATCOM-based plan for reducing power quality problems in an HVDC system. STACOM's integration with the HVDC system improves power quality problems like harmonics and voltage distortions. The simulation results show that STATCOM and HVDC Systems can be successfully integrated into large power system networks, which is beneficial. An overview of the wide range of topics related to High Voltage Direct Current (HVDC) transmission is given in this paper. An efficient HVDC design requires a thorough understanding of the underlying concepts, their application, and how HVDC systems are managed and regulated. Several limitations affect the operation and control of High Voltage Direct Current (HVDC) transmission, so before acting, one must carefully consider all available options. The simulation results demonstrate the successful and beneficial integration of STATCOM with Multigrid HVDC System for large power system networks. Therefore, conducting system testing under various conditions and assessing the system for limit violations using Power Flow features is imperative. The simulation of HVDC using STATCOM has been completed, resulting in improved voltage and current waveforms.

REFERENCES

[1] Satya Prakash, Roshan Nayak, “Simulation & Performance Analysis Of HVDC Multigrid Transmission System Using Statcom”, International Journal of Science, Engineering and Technology Research (IJSETR) Volume 4, Issue 3, March 2015.

[2] Haojun Zhu, Zexiang Cai, Haoming Liu, and Yixin Ni, "Multi-infeed HVDC/AC power system modelling and analysis with dynamic phasor application", 2005 IEEE/PES Transmission and Distribution Conference & Exhibition: Asia and Pacific Dalian, China.

[3] K Saichand and K.R.Padiyar, "Analysis of voltage stability in multi-infeed HVDC systems with STATCOM", 2012 IEEE International Conference on Power Electronics, Drives, and Energy Systems December 16-19, 2012, Bengaluru, India.

[4] Yi. Zhang, Aniruddha M. Gole, "Comparison of the Transient Performance of STATCOM andSynchronous Condenser at HVDC Converter" Stations IEEE.

[5] Hua-bo Shi, Tian-qi Liu, "HVDC and STATCOM Coordinate Modulation Damping Low-Frequency Oscillation", 2012 IEEE.

[6] P.K. Dash, M.A. Rahman, and P.C. Panda, "DYNAMIC ANALYSIS OF POWER SYSTEMS WITH MULTITERMINAL HVDC LINKS AND STATIC COMPENSATORS", IEEE Transactions on Power Apparatus and Systems, Vol. PAS-101, No. 6 June 1982.

[7] S. Bozhko, R. Li, R. Blasco-Gimenez, G. M. Asher, J. C. Clare, L.Yao, and C. Sasse, "STATCOM-controlled HVDC Power Transmission for Large Offshore Wind Farms: Engineering Issues", 1-4244-0136-4/06/2006 IEEE.

[8] Tatsuhito Nakajima, "Operating Experiences of STATCOMs and a Three-Terminal HVDC System Using Voltage Sourced Converters in Japan", 0-7803-7525-4/02/2002 IEEE.

[9] L. Xu, B.R. Andersen, and P. Cartwright, "VSC transmission operating under unbalanced AC conditions - analysis and control design", IEEE Trans. on Power Delivery, v 20, n 1, Jan. 2005, p. 427-34.

[10] M. O. Faruque, "Detailed modeling of cigré HVDC benchmark system using PSCAD / EMTDC and PSB /SIMULINK", IEEE Transactions on Power Delivery, vol. 21, no. 1, Jan 2006.

[11] B. R. Andersen and L. Xu, "Hybrid HVDC system for power transmission to island networks", IEEE Trans. on Power Delivery, v 19, n 4, October 2004, p. 1884-1890.

[12] Narain G.Hingorani & Laszlo Gyugyi," Understanding FACTS Concepts and Technology of Flexible AC Transmission Systems", Power Electronics Los Altos Hills, IEEE Press Wiley Interscience, John Wiley and Sons, Hoboken,2000

[13] K.R. Padiyar, "HVDC Power Transmission Systems: Technology and System Interactions", New Age International Publisher, 2008.

[14] Dennis Lee Hau Aik, Goran Andersson, "Voltage stability analysis of multi-infeed HVDC systems", IEEE transaction on Power Delivery, Vol 12, No.3, July 1997.

[15] Paulo Fischer, Jiuping Pan, Kailash Srivastava, Wilbur Wang, Chao Hong "Case study of a Multi-infeed HVDC system", PowerCon, New Delhi, India, Vol. 12, No.4, October 1997.