Review of Designing & Analysis of HVDC Transmission Line

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ABSTRACT

Presently power system operates under a high stress level which was neglected at the moment they were designed. The operating conditions of power system are being threatened form the reliability, controllability and security point of view. HVDC transmission brings a solution to have secure and improve the stability margins of power system. The characteristic like independent control of real and reactive power improves the power system stability and ensures an efficient power transfer. The paper presents different control strategy for Analysis & designing of HVDC Transmission Line a new modeling and control strategy of VSC-HVDC transmission system in order to improve system damping oscillations, and enhancing transient and voltage stability. This control strategy is based on a linear and bilinear state space deviation models. The structure of the control method is designed in order to minimize the number of the control loops (inner and outer control loops) in the classical strategy to one control loop for each output. These control loops are active power or DC voltage for the first output, and the reactive power for the other output.

Keyword: - *High Voltage Direct Current, High Voltage Alternating Current, thyristor, 6-pulse, converter.*

1. Introduction

Increasing trend of energy demand and its mitigation by use of several conventional and nonconventional energy sources and transportation of energy from generating station to remote areas is a great challenge. To serve the above purpose it is needed to have a bulk power transmission over a long distance through overhead transmission line and undersea cable, this becomes hectic in case of AC transmission due to high charging current and losses caused by capacitance. Problem related to interconnect the unsynchronized grids to the existing grid, where the voltage level and frequency is the main constraint which restricts the interconnection through an AC link. For the eradication of above problem, it is having a solution by using DC transmission, where a controlled DC transmission provides the flexibility for a bulk power transmission over a long distance through a DC link [2], [5]. Converter stations are being used at the generating end for AC/DC conversion in a controlled manner which enables a controlled power flow.

A rapid development and research on power electronics switches provides a better, efficient technique for control mechanism, hence control over power flow. HVDC transmission resides a two basic type of converter technology. Those are classical line commutated current source converter (CSCs) and self-commutated voltage sourced converters (VSCs) [3]. Classical HVDC technology employs line commutated current source converters with thyristor valve used as a base technology for DC transmission in 1950s. Where thyristors are not fully controlled switches, hence it put limitation to control mechanism used for controlled power flow. Voltage source converter based transmission technology introduces flexibility in power transmission, as it uses fully controllable switches like IGBT which provides one of the efficient control mechanisms for control of power flow. Both classical and VSC-HVDC are used for the applications like long distance transmission, underground and undersea cable transmission and interconnection of asynchronous networks. But from control point of view VSC-HVDC having more flexibility and efficient power flow mechanism, as it is capable of controlling both active power and reactive power independently of each other, to keep stable voltage and frequency. Particularly self-commutation, dynamic voltage control and black start capability allows VSC transmission technology to serve isolated loads on islands over long distance submarine cables [6]

Thyristor based classical HVDC mostly used for point to point large power transmission long It has certain disadvantage like commutation failure as thyristors can‟t be off immediately, and it requires 40 ~ 60 % reactive power supply of the total active power transmission. To have a solution IGBTs are used that can be switched off and on immediately, no commutation problem, active and reactive power control independently, no reactive power compensation required, filter requirement is less as to filter out high frequency signals from PWM, no requirement of telecommunication between two stations of VSC-HVDC system [7]-[9]. VSC -HVDC link consist of a back to back voltage sourced converters (VSCs), a common DC link, which includes a large DC capacitors and DC cables. The control strategy is being designed to coordinate the active power control between two station which is realized by controlling the DC side voltage of one converter where other converter control the active power.

New converter designs have broadened the potential range of HVDC transmission to include applications for underground, offshore, economic replacement of reliability-must-run generation, and voltage stabilization. Developments include higher transmission voltages up to ± 800 kV, capacitor-commutated converters (CCC) for weak system applications and voltage-sourced converters (VSC) with dynamic reactive power control. This broader technology range has increased the potential HVDC applications and contributed to the recent growth of HVDC transmission. Fig. 1 shows the Danish terminal for Skagerrak pole 3 rated 440 MW. Fig. 2 shows the ± 500 kV HVDC transmission line for the 2000 MW Intermountain Power Project between Utah and California.

Fig. 1. HVDC converter station with AC filters in the foreground and valve hall in the background

Fig. 2. ± 500 kV HVDC transmission line

Objective of this research is to design a VSC- HVDC back to back converter and its control strategy to enhance the dynamic stability of power system. So that a bulk power system can withstand to a wide variety of disturbances. It is desirable to design and operate so that most adverse possible contingencies do not result in uncontrolled and cascaded power interruptions. In this VSC- HVDC back to back converter is used along with the parallel AC transmission line and its various control strategies to ensure a faster active and reactive power flow control, hence stability.

2. Control Strategies of designing of VSC-HVDC

The PWM control strategy in VSC-HVDC system accommodating IGBTs was initially proposed in the early 1990s [17-20]. However, in these studies only the phase shift angle between output fundamental frequency positive-phase sequence voltage and AC bus voltage was set as a control parameter, ignoring the amplitude of fundamental frequency positive-phase sequence voltage. Therefore, independent control of active and reactive power was not realized at that time. In these early schemes separate facilities were required to control reactive power. Therefore these early studies did not fully demonstrate the technological superiority of the VSC-HVDC technology.

a simpler and straight-forward control strategy based on the power control concept is developed [10]. These control schemes were characterized by relatively low bandwidth and consequently these schemes are unable to damp various resonances that exist in the AC systems. Furthermore, these schemes did not have effective capabilities of limiting over current. Consequently, this control strategy is undesirable.

Vector current control is now widely employed worldwide. It has the characteristics power and reactive power control. Conventionally, it is realized through a hierarchical control structure including outer-loop controllers and inner current loop controllers (as shown in Figure 1-1b), within which a dq decoupling technique is applied [11]

the outer-loop controllers produce reference values for the faster acting inner-loop current-controllers, and typically, the sending-end converter controls the real power and the receiving-end converter regulates the DC voltage. However, it is sometimes the case that one end is designated for power flow control and the other end for DC voltage control irrespective of the direction of power flow. The reactive power at either end of the link is controlled separately by the respective converters. The control of reactive power is used to control reactive power directly or indirectly as a means of controlling the power factor or AC voltage at a designated bus. Due to the simplicity and robustness, double closed-loop vector oriented PI controllers have been utilized in compensating the system to achieve the desired performance. The inner-loop controllers employ feed-forward decoupled control to make the active- and reactive-current track the reference values produced by the outer-loop controllers.

Table 2.1: Different techniques for design VSC-HVDC transmission line model

Sr. No.	Name of Author & Year	Title of paper	Methodology	Claim by Author
1	Si-Ye Ruan, Guo-Jie Li, Xiao-Hong Jiao, Yuan Zhang Sun, T.T. Lie - 2006	Adaptive control design for VSC HVDC systems based on back steping method	The adaptive controller design for nonlinear characteristics of VSC-HVDC systems, which is based on backstepping method, considers parameters uncertainties. For an original high-order system, the final control laws can be derived step by step through suitable Lyapunov functions.	The design process is simple and clear because control laws can be derived step by step based on backstepping method. The proposed adaptive control contributes significantly to improved dynamic behaviors for VSC HVDC systems. Thus, the adaptive control design is effective for VSC-HVDC systems containing parameters uncertainties.
2	A. K. Moharana, Ms. K. Panigrahi, B. K. Panigrahi, and P. K. Dash -2006	VSC Based HVDC System for Passive Network with Fuzzy Controller	The basic features of proposedsystem used in VSC based HVDC systems are: 1) two rule base system is used. 2) allcontrollers are not selfcorrecting. At both stations error and change in error have been taken as input to the controller. Design of high pass filter with FFT analysis has also been proposed for a better dynamic performance of the function based fuzzy controller	With proposed control strategy, quick response and dynamic stability have been achieved for any kind of changes and high level control accuracy is attained at different operating condition.
3	H. S. Ramadan, H. Siguerdidja	Robust Nonlinear Control Strategy for	The controller"s design are based on the Sliding Mode Control (SMC) and Lyapunov"s control methodologies to deal with the	Although the controller based Lyapunov method is relatively simpler in implementation and its

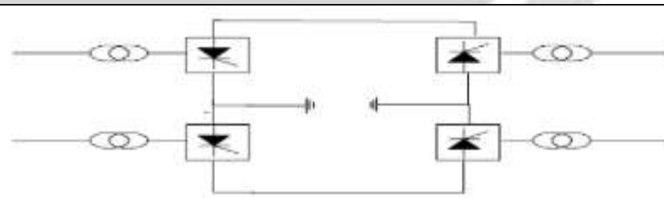
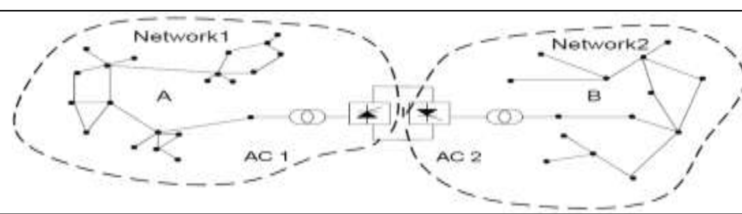
	ne and M. Petit -2008	HVDC Light Transmission Systems Technology	nonlinearities introduced by requirements to power flow and line voltage. First, the steady state mathematical model of the HVDC Light system is developed and the decoupled relationship between the controlling variables is investigated. Then, the SMC and Lyapunov control techniques are resorted to govern the DC link voltage and to control the active and reactive powers	derivation is more complex, controllers based on SMC are preferable due to their better dynamic behaviors and more attractive robustness.
4	Guanjun Ding, Guangfu Tang, Zhiyuan He, and Ming Ding -2008	New Tech of VoltageSource Converter (VSC) for HVDC Transmissin System Based on VSC	The origin of modular multilevel VSC and its essential working mechanism are clarified in detail. Then, the effective protection measures of submodule and the technology of controlled submodule capacitor voltages balancing are discussed.	The output ac voltages can be adjusted in very fine increments. It minimizes the generated harmonics and in most cases completely eliminates the need for ac filters. Furthermore, the small and relatively shallow voltage steps cause very little radiant or conducted high frequency interference.
5	Akshaya Moharana, and P. K. Dash -2010	Input Output Linearization and Robust Sliding Mode	Presents a robust nonlinear controller for VSC-HVDC transmission link using input–output linearization and sliding mode-control strategy. The feedback linearization is used to cancel nonlinearities & the sliding mode control offers invariant stability to modeling uncertainties due to converter parameter changes, changes in system frequency, and exogenous inputs.	The proposed controller is found to be robust, producing significant damping and a reduction of overshoots for a variety of operating conditions include short circuits at the converter buses, power reference changes for the rectifier and inverter, power reversal, low short-circuit ratio on the ac side, etc.

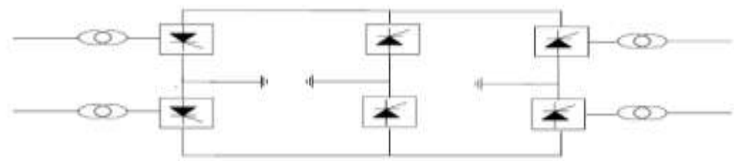
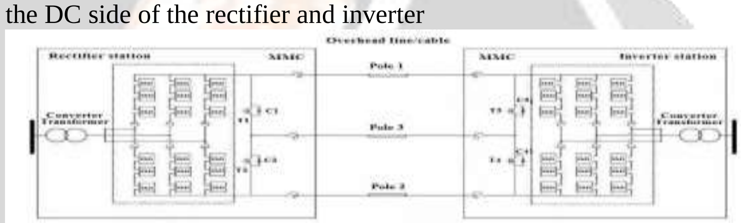
6	Grain Philip Adam, Khaled H. Ahmed, Stephen J. Finney, Keith Bell, and Barry W. Williams - 2013	New Breed of Network Fault Tolerant Voltage Source Converter HVDC Transmission System	Proposes a new breed of high voltage dc (HVDC) transmission systems based on a hybrid multilevel voltage source converter (VSC) with ac-side cascaded H-bridge cells. The proposed HVDC system offers the operational flexibility of VSC based systems in terms of active and reactive power control, black start capability, in addition to improved ac fault ride-through capability and the unique feature of current limiting capability during dc side faults. Additionally, it offers features such as smaller footprint and a larger active and reactive power capability curve than existing VSC-based HVDC systems, including those using modular multilevel converters.	The main advantages of the proposed HVDC system are: potential small footprint and lower semiconductor losses compared to present HVDC systems, low filtering requirements on the ac sides and presents high-quality voltage to the converter transformer, does not compromise the advantages of VSC HVDC systems such as four-quadrant operation; voltage support capability; and black start capability, which is vital for connection of weak ac networks with no generation and wind farms, modular design and converter fault management
7	Giovanni Beccuti, Georgios Papafotiou, and Lennart Harnefors - 2014	Multivariabl e Optimal Control of HVDC Transmission Links With Network Parameter Estimation for Weak Grids	The target is to develop a control method which, given the requested power and voltage values, yields an appropriate set of voltage references to be fed to the modulation scheme of the VSC. A parameter estimation scheme for the model employed in the model predictive control formulation is included.	to operate at high power levels with weak grid conditions. Although the control concept at the current stage of the work was not developed to the level of industrial implementation, it displays promising performance for very challenging operating settings for traditional controllers fail to even yield stable operation.
8	Mohamed Moez Belhaouane, Julian Freytes, Mohamed Ayari, Frderic Colas, Franois Gruson, Naceur Benhadj Braiek, and Xavier Guillaud - 2016	Optimal Control Design for Modular MultilevelC onverters Operating on Multi Terminal DC Grid	The proposes an advanced control strategy for Modular Multilevel Converters (MMC) integrated in Multiterminal DC grid. In this present work, a three terminal MMC-MTDC system connecting onshore AC systems with an offshore wind farm is setup. Firstly, the voltage droop control associated to the conventional cascaded controllers for MMC stations is studied, the dynamic behavior of the DC voltage is analyzed and some drawbacks are outlined. In order to improve the dynamic behavior of the controlled DC bus voltage and the stability of MTDC system, an optimal multivariable control strategy of each MMC converter is proposed and integrated in a voltage droop	The proposed control method allows reducing the oscillations and improves the DC bus voltage dynamics even for a lower droop parameters designed on static considerations. The advanced controllers associated to the classic droop control method improves MMC MTDC system stability and provides disturbance rejection.

			controller strategy.	
9	Mohamed Moez Belhaouane, Mohamed Ayari, Naceur Benhadj Braiek and Xavier Guillaud - 2016	Nonlinear Modeling and Control of a VSC HVDC Transmissio n Systems	Presents a new modeling and control strategy of VSC-HVDC transmission system in order to improve system damping oscillations, and enhancing transient and voltage stability. This control strategy is based on a linear and bilinear state space deviation models. The structure of the control method is designed in order to minimizethe number of the control loops (inner and outer control loops) inthe classical strategy to one control loop for each output. These control loops are active power or DC voltage for the first output, and the reactive power for the other output.	The reference inputs of active and reactive power and DC voltage can be tracked quickly using the feedback control strategy, and the active and reactive power of the VSC-HVDC system can be controlled independently.

3. HVDC Configuration system

In terms of connectivity HVDC transmission system, depending on the location, type and purpose of use, as well as the choice of cable, there are several configurations and types of HVDC transmission system. The main types of connections HVDC electricity transmission system are

Sr no	Configuration system	Parameter
1	Monopolar	 In this HVDC configuration the return line must be earthed, and can be connected to the return line of another converter station
2	Bipolar	 represents a parallel connection of two monopolar HVDC system for the transmission of electricity. The main advantages of bipolar HVDC transmission system configurations are continued operation in the event of failure, and the ability to change the flow of energy
3	Back-to-Back	

		It Consists of two converter stations located in the same location. The main characteristics (specificity) of this configuration are the fact that it does not use the DC transmission line of electricity. More specifically, within a configuration Back-to Back HVDC transmission system, the rectifier and the inverter are in the same transferring cell [1]. Back-to-back configuration of the HVDC transmission system is used and ensures the connection of two systems with different AC frequencies (asynchronous interconnections) and/or a second AC system and the same frequency
4	Multiterminal	 Consists of a transmission line/cable, and more than two of the converter which can be connected sequentially or in parallel The main advantage of the is to link different AC transmission systems.
5	Tripolar HVDC configuration.	Based on the use of the latest technologies MMC (Modular Multilevel Converter) converters. Specifically, within the structure of this configuration, the rectifier and inverter consist of a three phase six-bridge arms modular multilevel converter (MMC), and two converter valves are arranged on the DC side of the rectifier and inverter 

IV Proposed Methodology

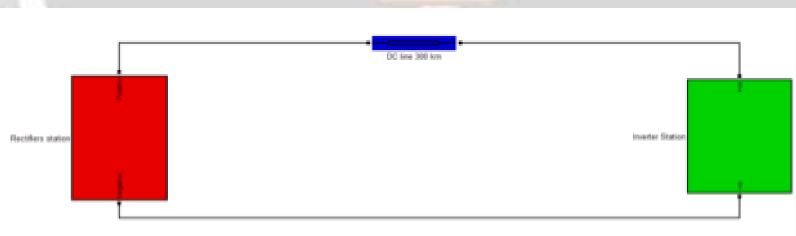


Figure 4.1: MATLAB simulation model for hvdc line power system includes rectifier station subsystem, inverter station subsystem and dc transmission line

From the various literature review of designing & Analysis of HVDC transmission line it observed that there are so limitation in efficiency and performance observed to overcome that we proposed the complete HVDC transmission line Simulink model in which red colour subsystem block is rectifier station and green colour subsystem block is inverter substation. Rectifier subsystem block connected with inverter station using DC link transmission line having distance 300KM

V Conclusion

High Voltage Direct Current systems are a relatively new mode of electricity transmission, which, due to their structure and characteristics provide a number of advantages. In comparison with the HVAC transmission systems, HVDC transmission systems provide transmission of large power to the extremely large distances, greater control power, connection of the system with a different frequency (asynchronous connection) and/or a system with the same frequency, as well as the connection of submarine power cables. High efficiency of electricity transmission, better control of voltage and power is provided by using different types of technology and thyristors and thyristor valves - ETT and LTT. The converter stations are the most commonly used power converters in HVDC transmission systems of the 6-pulse , proposed the complete HVDC transmission line Simulink model.

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