Review On Modular Multilevel Converter-based HVDC System Under Fault Conditions and Fault Detection

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ABSTRACT

Electrical energy in modern times is required in almost all commercial and industrial purposes. But in the case of HVDC systems the faults and protection mechanisms are not as developed as are for AC systems. This paper presents the fault analysis for a Modular Multilevel Convertor in HVDC system and a fault detection system, using MATLAB. Different DC & AC faults are analyzed. And the fault detection system is tested for robustness. DC & AC faults are different in nature which allows us to differentiate between them.

Keyword: *- High Voltage Direct Current (HVDC), Modular Multilevel Converter (MMC), Insulated Gate Bipolar Transistor(IGBT), Sub Module(SM), Matrix Laboratory(MATLAB)*

1. INTRODUCTION

For many years electricity is generated/produced in AC form. Then this electricity is transmitted and distributed to customers also in AC form. For transmission to long distances it's more beneficial to convert it to DC and then transmit the power. Although the initial cost is high in HVDC systems but for longer distances they are less than those of AC transmission systems and also lower losses when compared to AC systems. Moreover, HVDC causes less impact on the environment than High Voltage AC. HVDC is used for around 700 KM in case of overhead lines and 40 KM in case of underground lines. HVDC systems can also be used to connect two different grids operating on different frequencies. Also, grids in different countries/continents can be connected together to increase grid stability and reliability.

Modular Multilevel convertor (MMC) has many advantages flexible expandability configuration without the need for transformers, higher reliability, redundancy, low switching losses, high efficiency, low harmonic distortion in the output which allows for omitting bulky filters at the AC side and reduction of DC link capacitance. They also have some disadvantages like complex overall structure, circulating currents, complex control strategy, voltage fluctuation at low frequency.

Different types of faults may occur on both the AC and DC side of the MMC and therefore we need to study them and devise a fault detection system which can detect these faults. Also we have take into account the presence of different devices like STATCOM, UPFC and SSSC have on the impedance calculations. A simple relay is accurate enough for small, simple systems but when these systems contain high power devices, the distance relay has a tendency to under reach or over reach. The impedance increases/decreases due to the presence of these devices which will impact the working of traditional relay. For example, a device absorbs reactive power, then the measured impedance will be greater than the actual and it will operate in under reach or in another case if the device connected delivers reactive power, then the impedance measured will less than original and the relay will go to overreach.

1.1 HVDC SYSTEM

High-voltage direct current (HVDC) electric power transmission system (also called a power superhighway or an electrical superhighway)[1][2][3] uses direct current (DC) for electric power transmission, in contrast with the more common alternating current (AC) transmission systems.[4]

Long distance HVDC lines carrying hydroelectricity from Canada's Nelson River to this converter station where it is converted to AC for use in southern Manitoba's grid

Most HVDC links use voltages between 100 kV and 800 kV. However, a 1,100 kV link in China was completed in 2019 over a distance of 3,300 km (2,100 mi) with a power capacity of 12 GW.[5][6] With this dimension, intercontinental connections become possible which could help to deal with the fluctuations of wind power and photovoltaics.

HVDC allows power transmission between AC transmission systems that are not synchronized. Since the power flow through an HVDC link can be controlled independently of the phase angle between source and load, it can stabilize a network against disturbances due to rapid changes in power. HVDC also allows the transfer of power between grid systems running at different frequencies, such as 50 and 60 Hz. This improves the stability and economy of each grid, by allowing the exchange of power between previously incompatible networks.

The modern form of HVDC transmission uses technology developed extensively in the 1930s in Sweden (ASEA) and in Germany. Early commercial installations included one in the Soviet Union in 1951 between Moscow and Kashira, and a 100 kV, 20 MW system between Gotland and mainland Sweden in 1954.[8] Before the Chinese project of 2019, the longest HVDC link in the world was the Rio Madeira link in Brazil, which consists of two bipoles of ±600 kV, 3150 MW each, connecting Porto Velho in the state of Rondônia to the São Paulo area with a length of more than 2,500 km .

1.2 TYPES OF FAULT AND CONDITION

Major fault points of a typical HVDC system. The most serious fault of the converter is the short circuit fault; the short circuit will make the valve lose shut-off ability or the external insulation between the two ends of the valve is destroyed.

1) Positive pole to ground fault
2) Positive pole to Negative pole fault.
3) Single line to ground fault on the AC side
4) Double line to ground fault on the AC side
5) Triple line to ground fault on the AC side.
6)

2. MODULER MULTILEVEL CONVERTER

This section deals with MMC topology and the components used in a three-phase MMC. It consists of a DC input terminal, an AC output terminal and different converting submodules with one leg for each phase. There are two converting sub modules in the upper arm and lower arms also contain same submodules which are connected together with an inductor to filter high frequencies components from the arm current. MMC's are capable of bidirectional power conversion.

Modular multilevel converter (MMC) is an advanced voltage source converter applicable to a wide range of medium and high-voltage applications. It has competitive advantages such as quality output performance, high modularity, simple scalability, and low voltage and current rating demand for the power switches. The generalized configuration of a three-phase MMC is comprised of a DC terminal, an AC terminal, and a converting kernel involving three phase legs. Each leg/phase has two symmetric arms referred to as the upper arm and lower arm. The upper arm and lower arm contain a group of identical submodules connected in series together with a chock inductor to suppress high-frequency components in the arm current. The research interests of MMCs are primarily associated with the topologies, mathematical modeling, output voltage and current control, submodule balancing control, circulating current control, and modulation methods. And the incorporation of wideband gap (WBG) semiconductors are prospected to facilitate the MMC application with further advantages of high-voltage and high- power operations, low power losses, high efficiency, improved reliability, and reduced module size and cooling system.

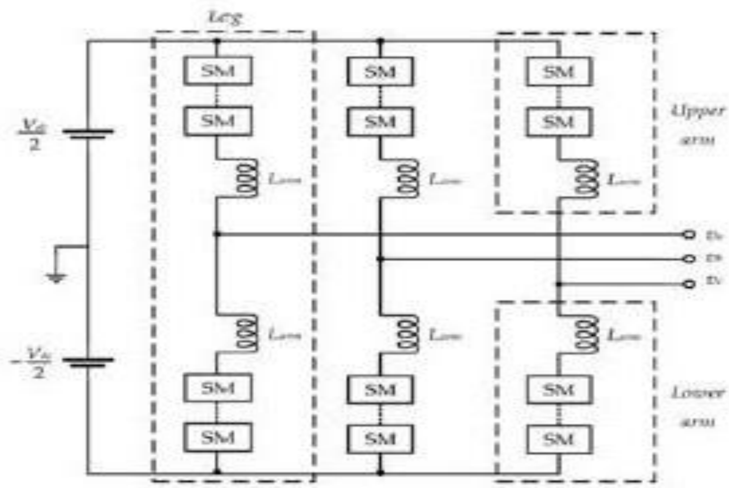

Fig. 1: General configuration of Three phase MMC

The SM or sub-module is an important part of the MMC. They can be classified as: 2 level SM (single source) and multilevel SM topology (multi-source). 2-level Topology: in the past 20 years many different topologies have been proposed. The most widely used topology is the half bridge SM due to its simplicity and low cost. It's comprised of 2 switches with diodes that are anti parallel coupled with a capacitor of floating type. The voltage in SM can be made zero depending on the state of the capacitor. It is for this reason sometimes this SM is also referred to as chopper.

3. OPERATING PRINCIPLE

Inside a 3 phase Modular Multilevel Convertor, every phase is divided in to two parts and each part has N no. of submodules which are connected together in series. They are also supplied with a DC source of ±320V. Inside a SM there are two IGBT switches and a free-wheeling diode which is connected in anti-parallel direction. During operation under normal conditions only one switch is ON at a time and the flying capacitor charges or discharges accordingly. The switch which is in ON state will only conduct and it depends on current direction, which is why it becomes important to define the different states in which the switches are which are ON, OFF and Blocked state which are defined as:

When the switch is ON, i.e., S1 is ON and S2 is OFF. In this state the total output voltage equals to the capacitor voltage and the current of the capacitor depends on the polarity of the current. (When current is positive the capacitor charges and vice versa.)

When the switch is in OFF, i.e., S1 is OFF and S2 is ON. The output voltage in this state is zero and voltage in the capacitor remains constant. There will be no charging or discharging of the capacitor in this state.

When in blocked state both the switches are turned OFF. The only possible path for current to flow is through the diodes. The capacitor will not discharge, but may charge if the current is positive.

The voltage in the blocked state is two times the input voltage. This happens because when all the SM's have their S1 switches in OFF state which results in phase voltage equals input DC voltage. The S2 switches must have the ability to block the voltage flowing across them. In essence all the switches should be able to block the DC voltage in their OFF state. The capacitors in the lower SM's should also be configured the same as the IGBT switches. As in the case the negative return current the upper switches or S1's should be able to block the flowing voltage in the capacitor. For this reason, capacitor voltage balancing becomes important.

4. SIMULATION MODEL

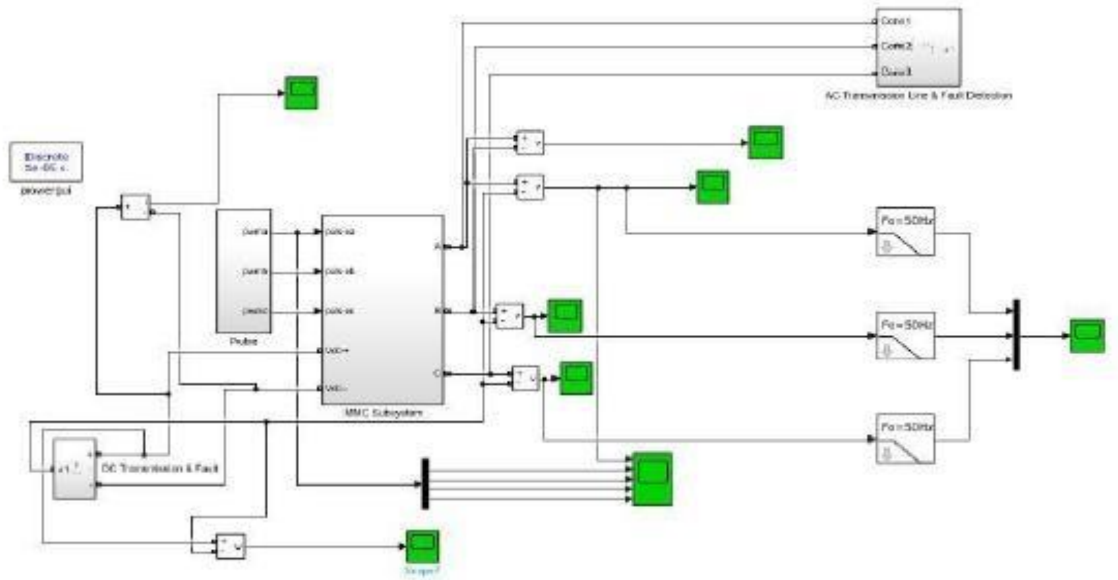

Fig. 2: Simulation Model

1) DC Transmission and Fault Subsystem: Consists of two D.C sources and 2 DC transmission line of 300 km each. Inside this subsystem there are two types of D.C fault which are simulated: Line to Ground Fault and Lineto Line fault are placed as shown in figure .
2) Pulse Subsystem: In this subsystem a sine wave is compared to a carrier wave which is used for creating switching signals for the operation of IGBT inside MMC
3) MMC subsystem: Consists of 8 different subsystems containing IGBT switches. With two for upper leg and two for lower legs. Hence there are four subsystems for each phase. As explained before different states the ON, OFF and blocked states signals come and switching happens as shown in figure .
4) AC Transmission and Fault Detection : There are three transmission line with length of 100, 88 and 12 KM respectively. Also consist of 4 different parallel and series RLC loads connected at both the ends of the transmission system
5) Mho relay for detecting faults this block consists of different subsystems such as

a) Filtering Block which consist of low frequency filters and PLL loop with a Fourier analyzer which is responsible for creation of two different signals one of voltage and another of current .

b) Second Block is the Fault detection Block which is responsible for reporting the faulty phase by selecting one loop by using K-Maps technique.

c) Impedance Measurement: This block compares of each phase with a value of margin factor to determine fault status.

5. APPLICATION

1. Modular Multilevel Converter Used for HVDC transmission line protection and fault detection in single phase AC transmission line.
2. Also used in high voltage AC transmission.

6. CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

HVDC transmission is widely used in the renewable power applications so it has many applications. This paper presents the workings of the modular multilevel convertors under normal conditions, under DC pole-pole faults, DC poleground faults, Single line-Ground faults and Double line to ground fauults. DC pole-pole fault is the most dangerous which is also analyzed. The fault charectrisitcs investigation has been done from the insatnt the fault is introduced. Also a fault detection mho relay is designed which uses pilot distance scheme to detect faults in three phase line quickly and one which uses impedance measurements for fault detection. This modelling of MMC, Control Block and different transmissions systems in done in MATLAB/ Simulink and the system has been tested in normal and fault conditions.

6.2 Future Scope

Future development prospects of MMC-based HVDC system Significant developments have been made in SM topologies, modeling, control, modulation techniques, and MMC applications over the past decade. In recent years, MMC has received more attention from various industrial applications and has become an integral part of new HVDC systems, integration of various RES into the grid, medium voltage drives, FACTs and storage systems. In addition, MMC-based HVDC systems have become an emerging technology that will lead to the development of the concept of super grids in the future. However, it suffers from several problems that must be resolved in order to expand its scope. This allows new SM topologies to be proposed to reduce the cost and size of the back-to-back MMC structure. With medium voltage inverters, there is a problem with the voltage ripple of SM capacitors. High value capacitors are needed to reduce these ripples during low frequency operation, which actually increases the cost and space of the entire system. To solve this problem, an efficient control method is needed. There are control and protection problems in the MMC-HVDC system; if they are met, a new search gateway could open. New control methods have to be developed in order to increase the output performance of the MMC and also to decrease the communication load. Further, enhanced hierarchical control architectures are also required to be proposed to integrate the system properly. To develop the large-scale HVDC system, more computationally efficient models of MMCs would be required. More research on the internal dynamics of MMCs would be needed to be carried out for the development the efficient methods to dampen the power oscillations in HVDC system.

A fast and robust protection system for MMC-HVDC systems is highly required. Therefore, there is still a need to develop fast and robust dc fault detection and location algorithms that can take the decision within the first few milliseconds. A combination of the different algorithms can provide better protection performance. Therefore, the combination of local measurement based and communication-based algorithms is still a challenge that can be further instigated. The use of only DC CBs for the protection of HVDC system is not an economical solution. The coordination DCCBs with MMC for the development of an effective protection system is highly recommended. However, coordinated protection strategies with decreased switching losses and overall cost are required to be developed for the future HVDC system.

The use of semiconductor material in MMCs plays a vital role in its performance. Nowadays, silicon-based semiconductor devices are widely used, but the combination of silicon and silicon carbide (SiC) (Leterme et al., 2019) could pave the way for a great future for the development of new SMs in future. In addition, the combination of these components can offer advantages such as the use of small capacitors, lower power losses, increased efficiency and fault handling capability, and full control under normal and high conditions fault.

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