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

Pranay Rout, Assistant Professor, Department of Electrical Engineering, NM Institute Of Engineering & Tech, Bhubaneswar
Ankita Panda, Assistant Professor, Department of Electrical Engineering, Krupajal Engineering College, Bhubaneswar
Asish Ashutosh Ray, UG Student, Department of Electrical Engineering, Krupajal Engineering College, Bhubaneswar
Deelip Kumar Sahu, UG Student, Department of Electrical Engineering, Krupajal Engineering College, Bhubaneswar

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.**

Keywords— Modular Multilevel Convertor, HVDC, Fault detection System

I. 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 its 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 ad vantages 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.

Different fault types that are possible in a system are:

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.

II. LITERATURE REVIEW

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 submodules 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.

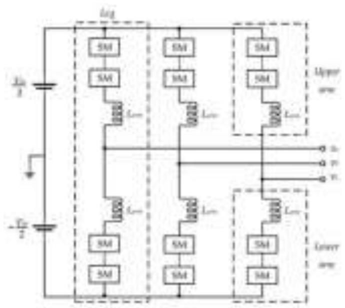

Fig. 1: General configuration of Three phase MMC

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.

III. 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.

A. Fault detection principle:

A pilot relay usually detects fault by calculating impedance difference between the current transformer and the place where the fault has happened. We need to find out different loops which adhere to one equation:

$$Z_n = \frac{V_n}{I_n} \tag{1}$$

The impedance measurement depends on two things, voltage (V_n) and current (I_n) which are measured. During fault conditions the impedance value is small than when at normal conditions.

This is the logic used in detecting faults in the AC side of the MMC. MHO type relay is one used in most applications because of three stepped zones. Different zones cover different sections of the line. For example, Zone 1 (Z1) covers 80% of the area and is the main protection and trips almost instantly. Then there are Zone 2 (Z2) and Zone 3 (Z3) which are kept for backup protection and they cover 130% and 200% of the transmission system. The operating timing of the relay can be configured in MATLAB to 0.2-0.35 sec and 0.3-0.45 sec respectively.

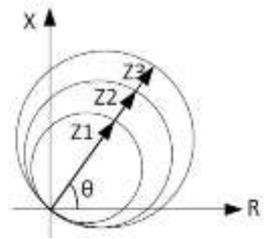

Fig 2: Different operating zones of a MHO type relay

Since the MMC will be used in a grid where other device are also present which operates at higher voltages like FACTS, UPFC, STATCOM, SVC and SVS regulators. The presence of these devices alters the impedance which could result in wrong calculations by the traditional distance relay creating a problem of under or over reach. The proposed model in this paper proposes a different scheme for detection of three phase by adding a communication channel which connects N number of relays together for better tripping and avoiding wrong detections.

IV. MODELLING OF THE PROPSED SCHEME

The model consists of different subsystems which are shown in Figure 3.

The different subsystems are as follows:

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 Line to Line fault are placed as shown in figure 4.

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 as shown in figure 5.

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 6

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 as shown in figure 7.

5) Mho relay for detecting faults: as it can be seen in figure 8, 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.

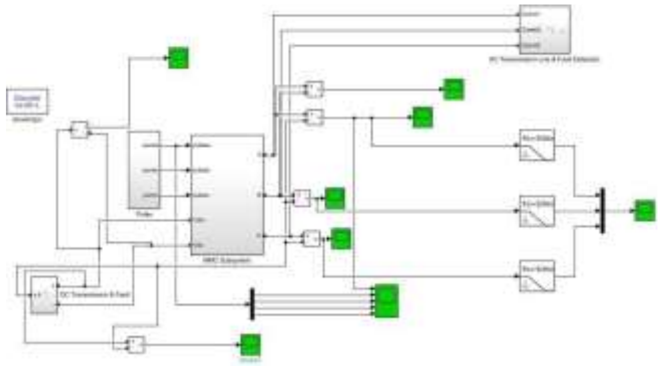

Fig 3: Main Model

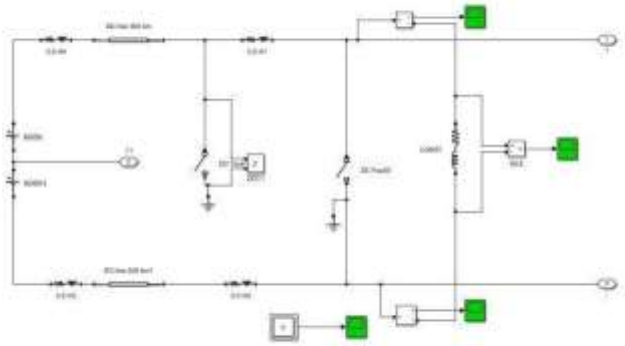

Fig 4: DC Transmission and Fault Subsystem

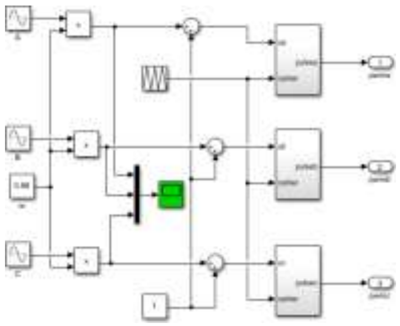

Fig 5: Pulse Subsystem

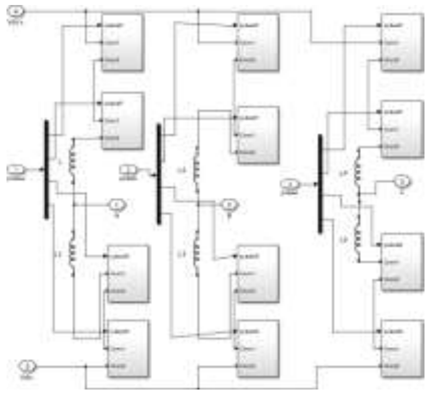

Fig 6: MMC Subsystem

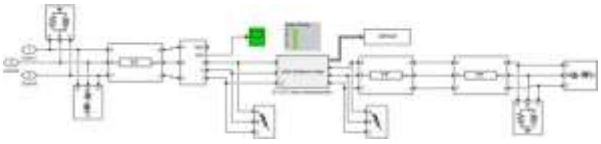

Fig 7: AC Transmission and Fault Detection

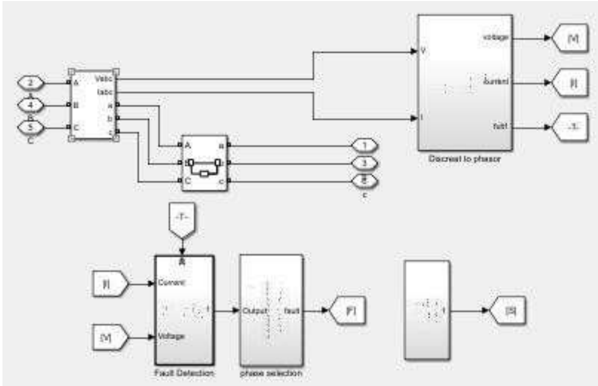

Fig 8: Fault Detection System

V. RESULTS

1. MMC Normal Operation:

In the normal state MMC operates normally and is being fed by a DC bi-polar link with transmission line of 300 km each at a voltage of Positive pole voltage of +600V and negative line -600V respectively. The output before and after filters are applied are shown in figure 9 and 10 respectively.

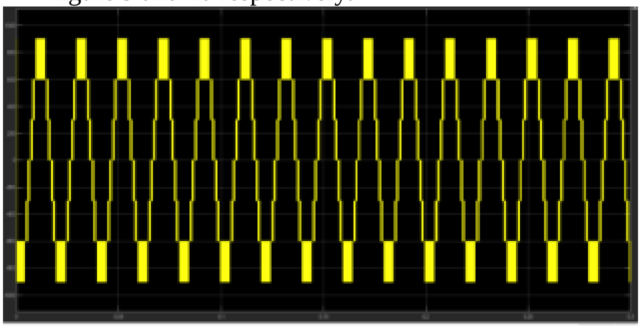

Fig 9: Three phase output of MMC under normal conditions (before applying filter)

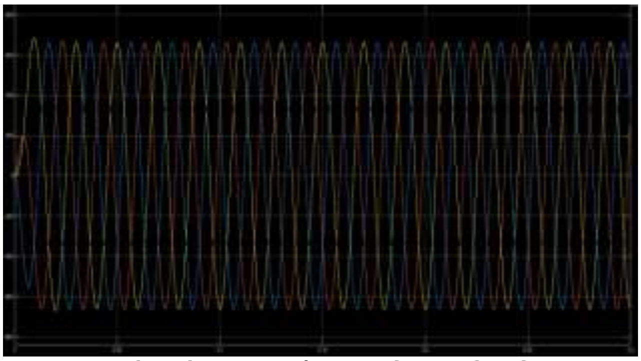

Fig 10: Three phase output of MMC under normal conditions

2. DC Line-Ground Fault

DC Line-Ground Fault occurs when Positive/Negative pole comes in direct contact with ground when the tower holding the line makes contact with ground or when line falls on the ground. The fault is created at 0.04sec and as we can see in Fig:11. That voltage becomes zero and current reaches a peak of 8A after slowly coming down because negative pole still continues to transmit power.

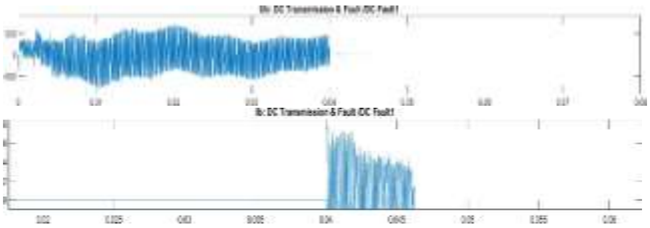

Fig 11: Output voltage of system under DC line-ground fault

3. DC Line-Line Fault

This type of fault occurs due to different polarity lines coming in contact i.e., positive and negative lines making a direct contact. Although this type of fault is rare but has the ability to seriously damage the power electronics devices that are connected in the grid and may also lead to a power interruption or blackout. In the simulation that was carried out the fault is triggered at 0.04 sec and as it can be seen in figure 12 that the fault current jumps to 60A and stays constant and voltage drops to zero.

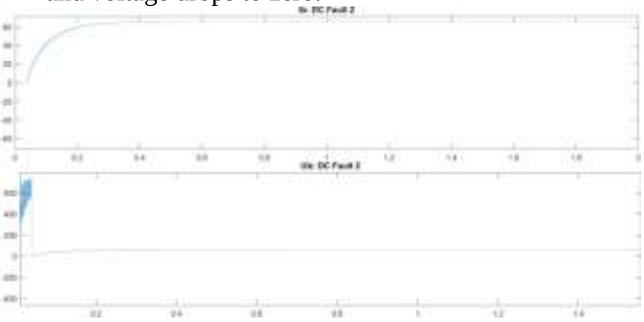

Fig 12: Output voltage and current of system under DC line-line fault

4. Single Line to Ground Fault

In the AC side we have a fault detection relay which can tell us the line in which fault occurs. The fault is set to occur at 0.04sec and outputs are shown in figure 13. The relay detects fault at phase B and neutral as it can be seen in Figure 14 and it takes a time of 0.011 sec

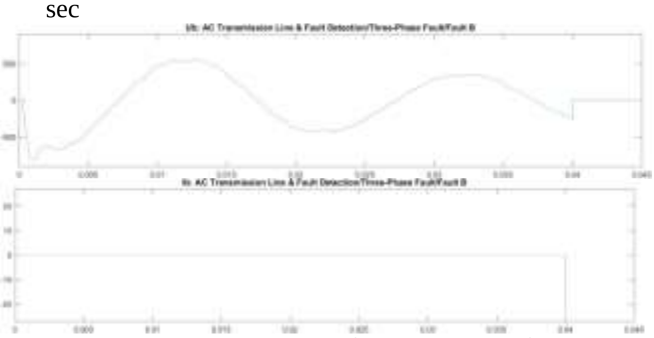

Fig 13: Output voltage and current of system under SLG fault

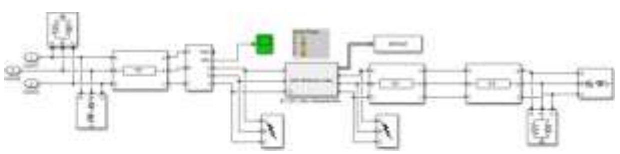

Figure 14: Relay indicating fault in phase B.

5. Double Line to Ground Fault

In this case we have simulted a double line to ground fault in phases A and C at 0.04sec and the output waveforms are as shown in figures 15. The time for fault detetction is 0.021 as can be seen in figure 16.

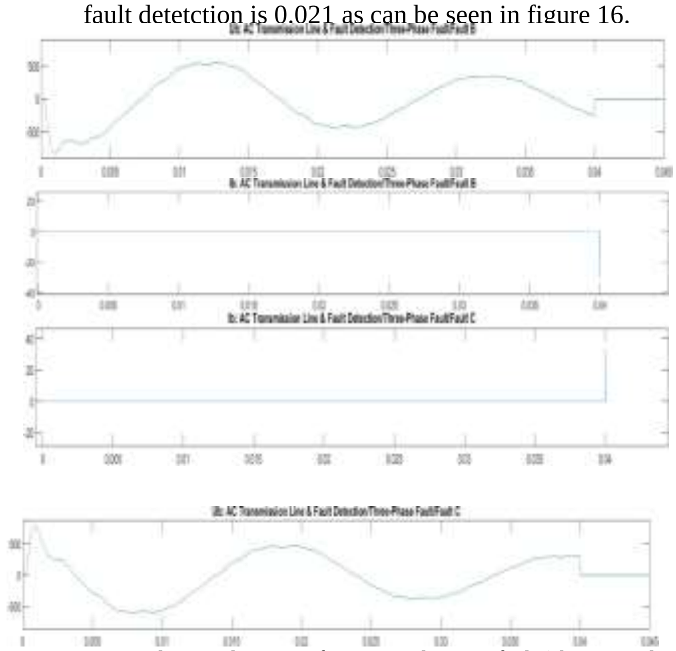

Fig 15: Output voltage and current of system under DLG fault.(phase A and C)

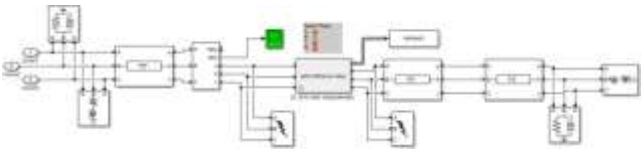

Fig 16: Realy indicating fault in phase A and C

VI. 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 pole-ground 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 transmsionn systems in done in MATLAB/ Simulink and the system has been tested in normal and fault conditions.

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