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Fast Fault Clearance and Automatic Recovery of Power Transmission in MMC-Based HVDC Systems

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Abstract: In this thesis, i explore the idea of the fault clearance in automatic manner without trip or shutdown the system in overhead transmission line of HVDC (High Voltage Direct Current systems) by using MMC(Modular Multilevel Converter). By using MMC the fault occurance in the particular line the mmc is built with the sub-modules the fault current is suppressed in various sub-modules.

Introduction

1.1 GENERAL

The HVDC technology is a high power electronics technology used in electric power systems. It is an efficient and flexible method to transmit large amounts of electric power over long distances by overhead lines or underground/submarine cables.it can be also used to interconnect asynchronous power systems. The first commercial HVDC connecting two AC systems was a submarine cable link between the Swedish mainland to the island of Gotland. The link was rated 20MW, 100KV and was commissioned in 1953. Nowadays, the HVDC is being widely used all around the world (K.R Padayar, 1999). Until recently HVDC based on thyristor, which is called traditional HVDC or classic HVDC , has been used for conversion from AC to DC and vice versa.

Recently a new type of HVDC has become available. It makes use of the more advanced semiconductor technology instead of thyristors for power conversion between AC and DC. The semiconductors used are insulated gate bipolar transistors (IGBTs), and the converters are voltage source converters (VSCs) which operate with high switching frequencies (1-2 KHz) utilizing pulse width modulation (PWM).The VSC-HVDC(VSC based HVDC) have been have been accepted as a feasible solution to implement efficient grid integration and power transmission for a large scale renewable generations over long distances.

In this thesis a new technology will be referred to as modular multilevel converter (MMC).Compared with conventional two-level converters or three-level neutral-point-clamped(NPC) converters ,a modular multilevel converter is more competitive since it can implement a high number of levels easily. Modular design, low switching frequency, high efficiency, and excellent output voltage waveforms are also advantages of MMC. It also provide a common dc bus. These distinguishing features make MMC-based HVDC (MMC-HVDC) very promising for extensive applications.

1.2 LITERATURE REVIEW

In recent years, a considerable amount of literatures have been published on MMC-HVDC transmission. There are few papers researching from this project view.

P.Bresesti and W.L.Kling (2007) presented a technical and economic analysis to evaluate the benefits and drawbacks of grid connecting offshore wind farms through dc link. A first case, concerning a 100-MW wind farm, is thoroughly investigated and cases of larger wind farms (200 and 500 MW) are presented. Three different trans- mission solutions are compared: 150-kV ac, 400-kV ac, and high- voltage dc based on voltage sourced converters(VSC-HVDC).After a brief over view of the features of these connection solutions, the related operational aspects are evaluated. An economic assessment compares the dc connection option to the ac alternatives, taking into account the investment, operation, and maintenance costs, and the negative valorization of losses and energy not supplied. Economic assessment includes sensitivity analyses of parameters, which could impact the 100-MW wind farm: distance, component costs, dc converter reliability, and dc converter losses.

N.Flourentzou and V.G.Agelidis (2009) reported an overview of VSC-based HVDC power transmission systems and also a multilevel converter topologies are presented also control and modelling methods are discussed.

J.Yang and J.E.Fletcher (2010) this paper analyses dc faults, their transients, and the resulting protection issues. Overcurrent faults are analysed in detail and provide an insight into protection system design. The radial wind farm topology with star or string connection is considered. The outcomes may be applicable for

VSCs in the multi-VSC dc wind farm collection grid and VSC-based high-voltage direct current (HVDC) offshore transmission systems.

R.Marquardt(2010) the novel concept of Modular Multilevel Converter (MMC) offers superior characteristics for these applications. Its operations for HVDC-systems is explained and investigated with respect to new requirements – including failure management in Multi-terminal-HVDC- Networks.

L.X.Tang and B.T.Ooi(2002) proposed a protection of VSC-multi-terminal HVDC against DC faults.

D.Soto-Sanchez and T.C.Green(2011) reported on a novel control scheme to regulate the capacitor voltages in a multi modular converter (MMC) topology which is suitable for HVDC transmission systems. The scheme is based on the use of the active positive sequence current component, to maintain balance between the AC-side and DC-side powers, and the active and reactive negative sequence components, to exchange energy from the capacitors of one phase to those of another phase.

N.Ahmed and S.Norrga(2012) proposed a prospects and technical challenges for future HVDC Super Grids. Different topologies for a Super Grid and the possibility to use modular multilevel converters (M2Cs) are presented. A comprehensive overview of different sub-module implementations of MMC is given as well as a discussion on the choice between cables or overhead lines, the protection system for the dc grid and dc-side resonance issues.

1.3 OBJECTIVE OF THE THESIS

The main objective of the thesis is to develop a protection of non-permanent faults andautomatic recovery of power transmission on DC overhead linesusing modular multilevel converter (MMC) based HVDC systems.

1.4 ORGANIZATION OF THE THESIS

This thesis is organized in five chapters and appendices.

Chapter 1: In this chapter deals with the basics of the preferred protection scheme of dc overhead lines by using MMC.

Chapter 2: In this chapter presents a brief description of the voltage source converter based HVDC and conventional two-level converters, three level neutral-point clamped converters.

Chapter 3: In this chapter presents a overview of modular multilevel converter (MMC-HVDC) and various modules of MMC.

Chapter 4: In this chapter simulation studies related to the using MMC-HVDC and simulated results using PSCAD/EMTDC.

Chapter 5: Reviews the entire works done in the course of the project and presents the future work.

Voltage Source Converter

2.1 INTRODUCTION

A voltage source converter is a device connected between a dc-voltage network and an ac voltage network and is subjected to forced commutation for transmitting electric power between the voltage-source dc-voltage and ac voltage networks connected thereto.one application of VSC converters is in High Voltage Direct Current (HVDC) applications, which they offer a plurality of considerable advantages. Of these advantages can be mentioned that the consumption of active and reactive power may be controlled independently of each other and that there is no risk of commutating errors in the converter and hence no risk of commutating errors being transferred between different HVDC links. Brief description of Conventional two level converters and three-level neutral-point-clamped converters.

2.2 OVERVIEW OF VSC TRANSMISSION TECHNOLOGY

Since introduction in the early 1950s, HVDC technology has undergone continuous development, particularly in the areas of converter switches and controls. Today HVDC schemes provide reliable, efficient and cost effective solutions for many applications. The use of modern techniques have made it possible to obtain stable operation for HVDC schemes connected to much weaker ac networks than was previously possible.

HVDC POWER transmission systems and technologies associated with the flexible ac transmission system (FACTS) continue to advance as they make their way to commercial applications. Both HVDC and FACTS systems underwent research and development for many years, and they were based initially on thyristor technology and more recently on fully controlled semiconductors and voltage-source converter (VSC) topologies. The ever increasing penetration of the power electronics technologies into the power systems is mainly due to the continuous progress of the high-voltage high- power fully controlled semiconductors. The fully controlled semiconductor devices available today for high-voltage high-power converters can be based on either thyristor or transistor technology. These devices can be used for a VSC with pulse width modulation (PWM) operating at frequencies higher than the line frequency. These devices are all self-commuted via a gate pulse. Typically, it is desirable that a VSC application generates PWM waveforms of higher frequency when compared to the thyristor-based systems. However, the operating frequency of these devices is also determined by the switching losses and the design of the heat sink, both of which are related to the power through the component. Switching losses, which are directly linked to high-frequency PWM operation, are one of the most serious and challenging issues that need to be dealt with in VSC-based high-power applications. Other significant dis- advantages that occur by operating a VSC at high frequency are the electromagnetic compatibility/electromagnetic interference (EMC/EMI), transformer insulation stresses, and high- frequency oscillations, which require additional filters. HVDC and FACTS systems are important technologies, sup- porting in their own way the modern power systems, which, in many cases, are fully or partially deregulated in several countries (Nikolas Flourentzou, 2009). In the near future, even higher integration of electrical grids and market-driven developments are expected, as for in- stance, countries in the Middle East, China, India, and South America require infrastructure to power their growth and inter- connection of "island" grids.

VSC Transmission has a number of technical features that are superior to those of LCC HVDC schemes and make it especially attractive for the following applications:

- Feeding into passive networks
- Transmission to/from weak ac systems
- Enhancement of an AC system
- Land cable systems
- Supply of offshore loads
- Connection to wind farms(on-shore or off-shore) or wave power generation
- In-feeds to city centers
- Multi-terminal systems continuing development

2.3 VOLTAGESOURCECONVERTER–HVDC

HVDC transmission system based on voltage –source converters (VSCs), by themselves, are defenceless against dc faults.

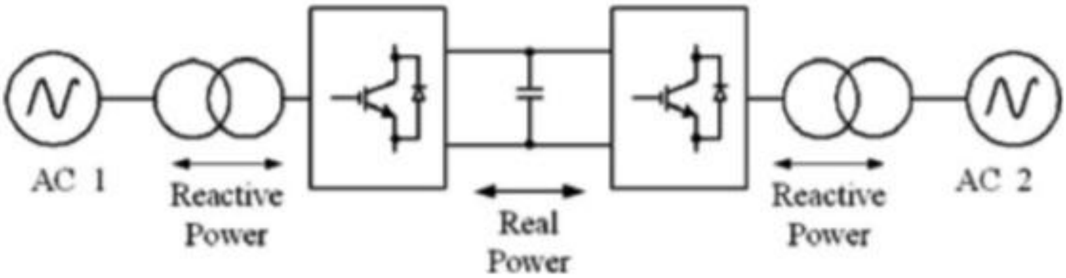

Figure 2.1 HVDC system based on VSC technology built with IGBTs

VSC-HVDC systems represent recent developments in the area of dc power transmission technology. VSC-based PWM-controlled HVDC system using IGBTs was installed in march 1997. The VSCs are more vulnerable to line faults, and therefore, cable are more attractive for VSC-HVDC applications.

A basic VSC-HVDC system comprises of two converter stations built with VSC topologies (see Fig. 2.1). The simplest VSC topology is the conventional two-level three-phase bridge shown in (Fig. 2.2). Typically, many series-connected IGBTs are used for each semiconductor shown (see Fig.2.6) in order to deliver a higher blocking voltage capability for the converter, and therefore in-crease the dc bus voltage level of the HVDC system. It should be noted that an antiparallel diode is also needed in order to ensure the four-quadrant operation of the converter. The dc bus capacitor provides the required storage of the energy so that the power flow can be controlled and offers filtering for the dc harmonics. Each phase leg of the converter is connected through a reactor to theac system. Filters are also included on the ac side to further reduce the harmonic content flowing into the ac system. One voltage is generated by the VSC and the other one is the voltage of the ac system. At the fundamental frequency, the active and reactive powers are defined by the following relationships, assuming that the reactor between the converter and the ac system is ideal (i.e., lossless):

P $= Vssin\frac{\delta}{Xl}Vr$ (2.1)

$$Q = \text{Vscos}\delta - \frac{\text{Vr}}{\text{Xl}} Vr \qquad (2.2)$$

Where δ is the phase angle between the voltage phasors of Vs and Vr at the fundamental frequency.

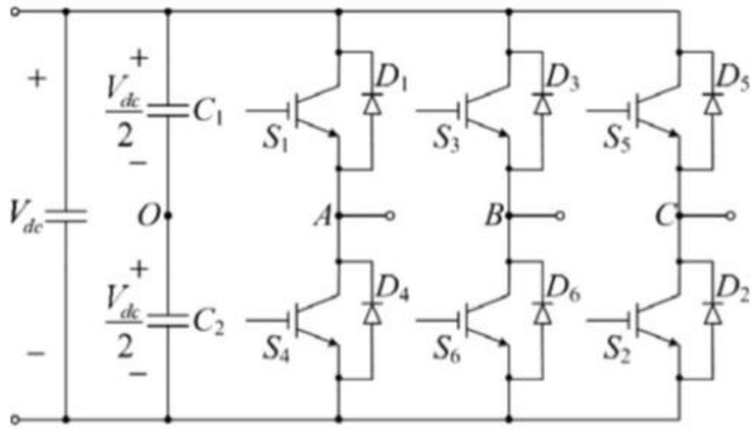

Figure 2.2 conventional three phase two-level VSC topology

The VSC-HVDC system can also be built with other VSC topologies. The converter is typically controlled through sinusoidal PWM (SPWM), and the harmonics are directly associated with the switching frequency of each converter leg. (Fig. 2.3) presents the basic waveforms associated with SPWM and the line-to-neutral voltage waveform of the two-level converter (see Fig. 2.2).

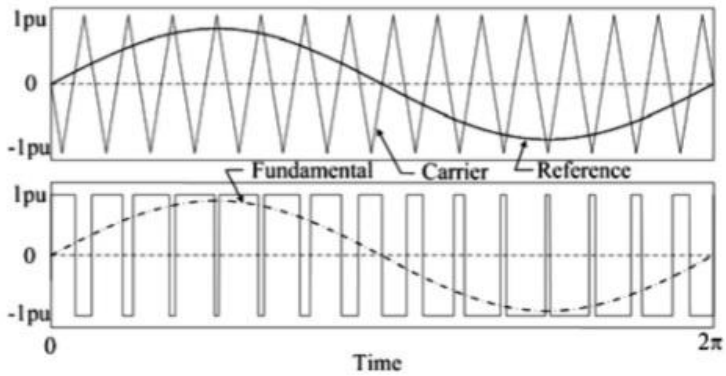

Figure 2.3 Two-level sinusoidal PWM method: reference (sinusoidal) and carrier (triangular) signals and line-to-neutral voltage waveform.

The entire active-reactive power area where the VSC can be operated with 1.0 per unit (p.u).The diagram representation given by fig(2.4).

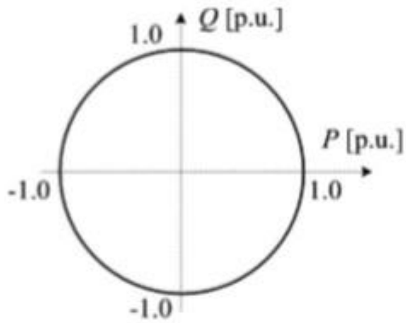

Figure 2.4 Active-reactive locus diagram of VSC-based power transmission system.

2.4 CONVENTIONAL MULTILEVEL CONVERTERS

There are numerous multilevel solid-state converter topologies are reported. However, there are two distinct topologies, namely, the diode-clamped neutral- point-clamped (NPC) converter (see Fig. 2.5) and the flying capacitor (FC) converter (see Fig. 2.6). For clarity purposes, three-level and five-level PWM voltage waveforms on the line-to-neutral basis are shown in Figs. 2.5(a) and 2.6(a), respectively. Contributions for selected topologies that can be used to build an HVDC system were made in numerous technical papers and are not limited (A.Lesnicar et al 2003). Specifically, PWM- controlled HVDC concepts based on the three-phase two-level converter were reported using GTOs. A similar system was developed and reported using IGBTs and DSP control.

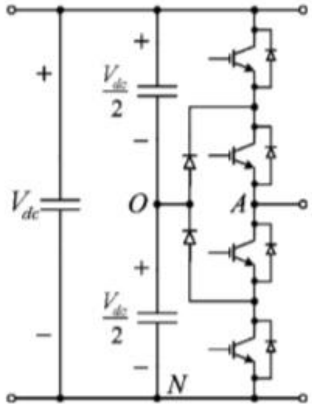

Figure 2.5 NPC phase leg

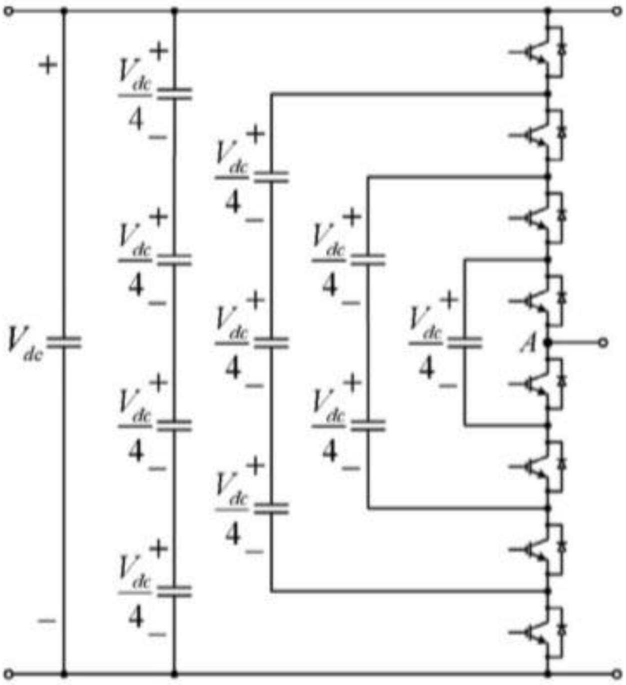

Figure 2.6 five-level FC VSC phase leg

Using modular approach and phase-shifted SPWM concepts, a number of advantages can be gained as far as the harmonic performance of the overall VSC-HVDC system is concerned. The modular multilevel converter using half-bridge cascaded connections that seems to be more suitable for different number of voltage levels is presented in and examined for HVDC applications.

2.5 APPLCATIONS

Some areas where the VSC technology will be useful are:

- In environmentally sensitive locations, i.e. city centers

- Converting ac to dc,
- Adding capacity with dc loads, and
- Control of power flow.

2.6 SUMMARY

This chapter described about the fundamentals and operation of VSC-HVDC and also described the conventional multilevel converters.

MODULAR MULTILEVEL CONVERTER

3.1 INTRODUCTION

The modular multilevel converter based high voltage direct converter (MMC-HVDC) technology active positive sequence current component, to maintain balance between the AC-side and DC-side powers. The environmental concerns over the use of fossil fuels, as well its limited availability, is leading to the increase use of methods of clean energy production to meet the energy demand. Harvesting of renewable energy resources, such as wind, in large off-shore installations, is believed to be one of the most immediately available methods for bulk energy production. The HVDC power conversion technology plays a fundamental role on this approach as it enables efficient transport of bulk power over long distances, which may be the general case of large off-shore wind farm installations. This has renewed the interest of industry for developing VSC-based HVDC systems in the order of 1000 MW. In this, the modular multilevel converter (MMC) implementation approach is gaining much attention by main manufactures as it allows a reduction in the power losses of the converter and in the physical size of the installation, compared to the standard VSCs whose valves use series connected devices such as IGBTs. The MMC-HVDC is very promising for extensive applications (N.Ahmed et al 2012). Main technical and economic aspects for the development of multilevel converters are:

- Modular realization: scalable to different power- and voltage levels - independent of the state of the art of fast developing power devices.
- Multilevel waveform: expandable to any number of voltage steps- dynamic divisions of voltage to the power devices - low total harmonic distortion.
- High availability: - use of approved devices - redundant operation.
- Failure management: fail safe operation on device failures - avoidance of mechanical destruction (high current magnetic forces and arcing).
- Investment and life cycle cost: - standard components - modular construction (A.Lesnicar et al 2003).

3.2 OVERVIEW OF MMC TRANSMISSION TECHNOLOGY

A standard MMC uses the half-bridge module to implement converter valves. Therefore, AC-side voltage magnitude of the MMC is constraint to be smaller than half DC-side voltage, otherwise the reverse diodes provides an uncontrolled conduction path from the AC- to the DC-side, leading to a short circuit which is only limited by the interface inductors. This will occur during a DC system disturbance that severely depresses DC-link voltage such as a short circuit on the DC transmission line. In contrast, H-bridge modules can output a bipolar voltage. This enables the H-bridge MMC to operate with zero, as expected during a DC-side fault, or even negative DC-link voltages. Therefore, the H-bridge MMC is capable of controlling both AC-side and DC-side current independent of the AC- and DC- system voltages, within rated values. This allows the H-bridge MMC to ride-through DC system outages, one of the mainissues of existing VSC-based HVDC systems. Main disadvantages of the H-bridge MMC, as compared to the half-bridge MMC, are that it roughly requires twice as many switching devices and it roughly incurs in twice as much power losses. However, the H-bridge MMC may prove practical when DC-side fault becomes an issue and alternative solutions involve the use of solid-state DC circuit breaker. Proper operation of an MMC rectifier/inverter requires adequate control of all of the capacitor voltages in the MMC. Tight balance between the active power drawn from the AC-side and that delivered to the DC-side of the converter, and vice-versa.

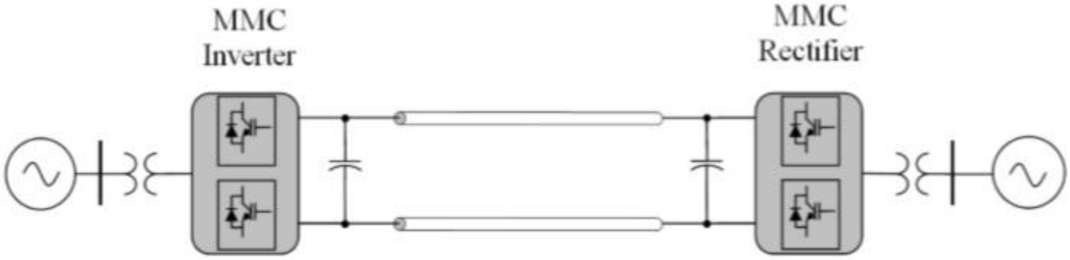

Figure 3.1 MMC based HVDC system

This work addresses the design of both the internal and external control system for an MMC-based transmission system applying the series string of H-bridge converters as converter valve (D.Soto-Sanchez et al 2012).

3.3 CIRCUIT MODEL OF MMC AND ITS SUBMODULE

The circuit diagram of a three-phase MMC is shown in figure 3.2.

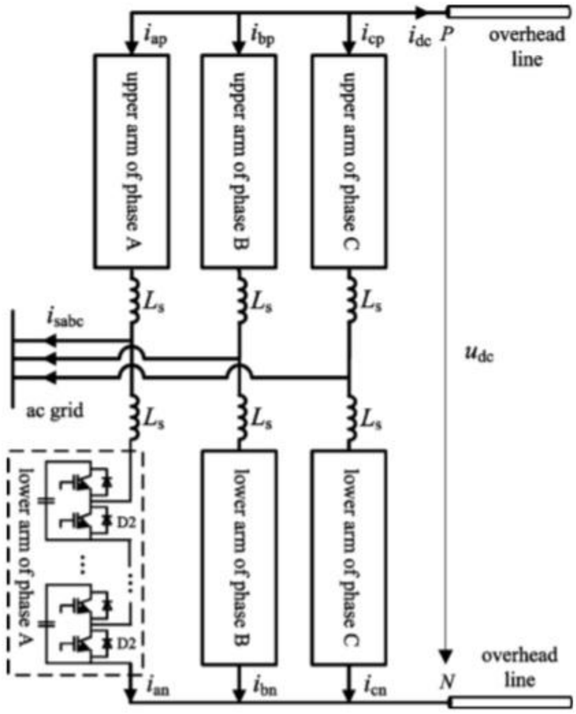

Figure 3.2 circuit diagram of MMC

A suitable and simple realization of the sub module is given in Fig. 3.3. The interface is composed solely of two electrical terminals and one bi-directional fibre-optic interface. This reduces the costs for manufacturing and maintenance, too. The voltage of any submodule can be freely controlled by software. The individual voltages of the submodules may even be chosen unequal. This can be used to increase the number of resulting voltage steps (e.g. together with PWM-operation). In contrast to the conventional VSI a common central capacitive storage is for the concept of MMC dispensable. This advantage eases the protection of the converter against mechanical destruction in case of a short circuit, significantly. In addition, a defective submodule can be replaced by a redundant submodule in the arm by control action without mechanical switches. This results in an increased safety and availability.

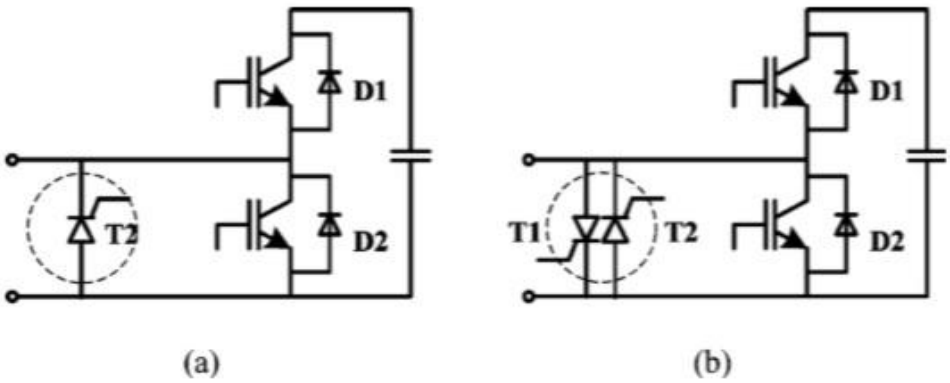

Figure 3.3 Structure of an MMC submodule with a bypass switch. (a) Single thyristor switch. (b) Double thyristor switches.

The voltages of the capacitors are periodically measured with a typically sampling-rate in the millisecond-range. According to their voltage the capacitors are sorted by software. In case of positive current the required number of submodules, determined by output state controller, with the lowest voltages are switched on. Therefore, the selected capacitors are charged. When the current in the corresponding arm is negative, the demanded number of submodules with highest voltages are selected. By this method, continuous balancing of the capacitor voltages is guaranteed. Inherently, this concept supports an optimized utilisation of the stored energy and evenly distributed power loses for the installed electrical devices. Additionally, the power losses can be kept low by switching the submodules solely when a change of the output state is requested.

3.3.1 TYPES OF MULTILEVEL CONVERTERS

In comparison to two-level converters, the switching frequency per switch of multilevel converters is substantially lower. Hence, multilevel converters may have significantly lower losses. The existing multilevel topologies are categorized as

- Diode clamped or neutral point clamped (NPC)
- Flying capacitors or capacitor clamped (FC)
- Cascaded H-bridge with separate dc sources
- Modular multilevel cascaded bridge converter (MMC) (without separate dc sources)

For higher number of levels the NPC converter requires high numbers of clamping diodes, which makes its structure quite complex. Also voltage balancing is a challenge with a high number of levels. Similarly, for higher number of levels the capacitor clamped multilevel converter topology requires a high number of capacitors with very high overall energy storage capability. The capacitors hence become bulky and expensive. For active power transmission, the inverter control becomes complicated. Furthermore, the construction becomes complicated and more complex as the number of levels increases. For cascaded H-bridge converters finally, separate dc sources are needed which makes its application limited.

3.3.2 MODULAR MULTILEVEL CONVERTERS

The MMC that was proposed by Marquardt and Lesnicar, is now getting popularity due to its advantages over the conventional topologies. As shown in Fig. 3.4(a), the MMC is highly scalable with respect to the number of levels. The basic component of an MMC is called a submodule. The number of submodules can be increased or decreased as the number of levels increases or decreases to get the desired output voltage. Three submodule topologies that have been proposed for MMC are the half bridge submodule (HBSM), full bridge submodule (FBSM) and clamp double submodule (CDSM),(Xiaoqian Li et al 2013).

1) HBSM: It is mainly composed of two IGBT switches, two anti-parallel diodes and a dc storage capacitor C_0 as shown in Fig. 3.4(b). The terminal voltage of each submodule can either be switched to zero or a voltage V.

2) FBSM: It consists of four IGBTs with anti-parallel diodes and a capacitor as shown in Fig. 3.4(c). This topology allows positive, negative as well as zero voltages.

3) CDSM: In normal operation CDSM shown in Fig. 3.4(d) represents two equivalent HBSMs. The half bridges are connected positive terminal to negative terminal so the insert and bypass switch positions are interchanged.

In an MMC these submodules are connected in cascaded style which gives the freedom to connect as many modules required without increasing the complexity of the circuit. The converter arm represents a controllable voltage source controlled with modulation techniques to get the desired output. The main advantages of MMC (regardless of submodule implementation) are

- The internal arm currents are continuous.
- The inductors inserted in the arms limit the ac-side current in case of a short circuit at the dc side.
- No separate energy sources are required for submodule capacitors.
- No common dc link capacitor is required.

One manufacturer makes use of stacked press-pack IGBTs. In this case MMC is called cascaded two-level (CTL) converter.

For two-level or three-level converters with series connected switches operating at higher voltages, voltage balancing is a major challenge as it requires

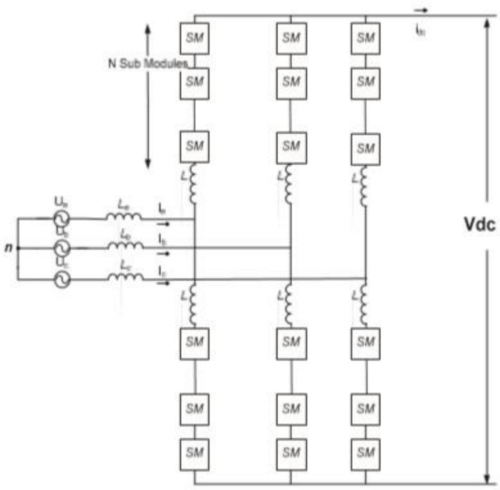

Figure 3.4(a) Modular multilevel converter

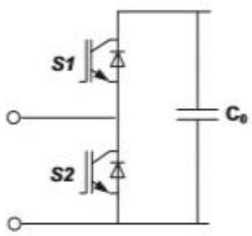

Figure 3.4(b) Half bridge submodule

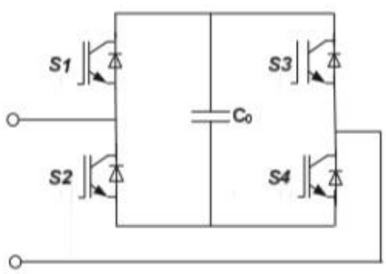

Figure 3.4(c) Full bridge submodule

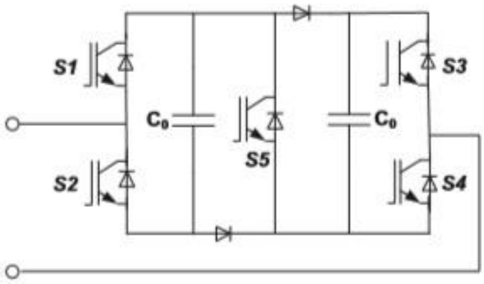

Figure 3.4(d) Clamp double submodule

Extremely precise control of hundreds of simultaneously switching devices within a valve. For MMC the equivalent task is tobalance the voltage across the individual submodule but at a slower time scale. The advantages of MMC over other existing converter topologies probably makes it most suitable candidate for HVDC grids.

The losses in two-level VSC stations are around 1.6% of the rated transmission capacity and around 70% of these are dissipated in the IGBT valves. With MMCs the valve losses are expected to be much lower. The choice of submodule implementation has a significant effect on valve losses. In, it is shown that the conventional HBSM with IGBTs has around 0.5% valve losses of rated power, while CDSM and FBSM implementation approximately give 35% and 70% more losses respectively. Hence, with reference to losses, the HBSM implementation for MMCs would be preferred in future SuperGrids.

3.4 PRINCIPLES OF DC-LINK FAULT PROTECTION

The dc-link short-circuit fault, the diode D2 in each submodule will create a path for fault current.Fig. 3.5(a) demonstrates a possible fault current path and the rectifier mode of MMC during the dc-link fault. It should be noted that the on state thyristor does not change the rectifier path. A single thyristor is usually enough if the aim is just to protect the diode from overcurrent. In this paper, in order to make MMC able to quickly clear the fault current and restart power transmission after non-permanent faults on dc overhead line, double thyristor switches are alternatively employed as shown in Fig. 3.3(b). The two thyristors (T1 and T2) are controlled by the same gate signal. During normal operation, the thyristor switches are kept in off state condition. During the dc-link fault, the thyristor switches are switched on. Since bidirectional thyristor switches are employed, not only is the fault current transferred from diodes to thyristors, but also the aforementioned diode freewheeling effect can be eliminated, which makes it possible to extinguish the dc-link fault current. Since using a single protection thyristor is common in assembling MMC power module in real industrial applications, adding one more thyristor to form the double thyristor switch merely causes a slight increase in cost. And the double thyristor switch causes no extra loss during normal operation. Therefore, the proposed protection scheme is cost-effective, compared with the dc CB solution and the full-bridge submodule (FBSM) or double-clamp submodule (DCSM) solution. It should be noted that both thyristors in the double thyristor switch have to withstand high dv/dt even during normal operation, since they are in parallel connection with the MMC submodule. Therefore, both thyristors are required have the capability of bearing high dv/dt. A snubber circuit is also essential to prevent damage due to over- voltage spike and dv/dt.

3.5 EQUIVALENT CIRCUIT DIAGRAM OF MMC DURING THE DC-LINK FAULT

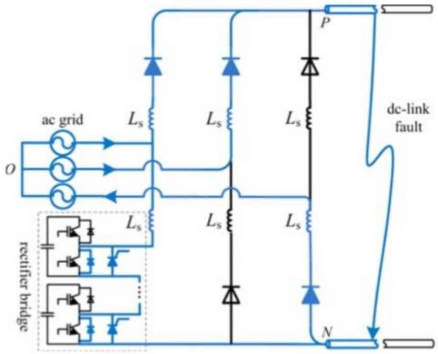

Figure 3.5(a) MMC with single-thyristor-switch Sub modules

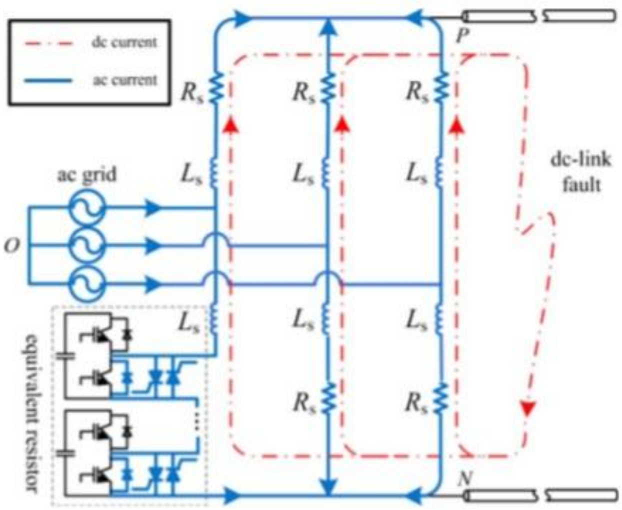

Figure 3.5(b) MMC with double-thyristor-switch submodules

3.6 PRINCIPLE OF AUTOMATIC RECOVERY

After the dc-link current decays to zero, the ac grid stillfeeds the ac short-circuit current through MMC arms. This ac fault current can be cut off simply by removing the gate signals for all thyristor switches. For each arm, the thyristor switches will be naturally turned off when the fault current of this arm hits zero. Accordingly, within one period, all thyristor switches can be dependably turned off, and the three-phase ac short-circuit currents are also cleared. After all thyristor switches are turned off, all of the IGBTs of MMC are still blocked, and MMC operates in a rectifier mode. The ac grid will re-energize the dc capacitors, and the dc-link voltage is able to be quickly rebuilt. Since the ac CB is still closed, MMC can operate in a converter mode again and restart power transmission simply by deblocking all IGBTs. MMC is able to be restarted, and the power supply is able to resume immediately and automatically.

3.6.1 COORDINATION WITH AC-GRID PROTECTION

The proposed protection scheme should coordinate with ac-grid protection to avoid opening the ac CB during the protection process. Generally, a critical tripping time exists which matches the voltage and current level of the ac grid for the ac CB. Using the proposed protection scheme, it takes more than five times the time constant T in to clear the dc short-circuit current. The time constant T depends on R_d, R_S, L_S, and Ld. And it takes less than one line frequency period to clear the ac short circuit current. Therefore, the total protection time should be shorter than the critical tripping time of the ac CB after fault detection. It is noted in that the time constant is partially determined by Rd. The total protection time increases when the value of gets smaller. In most cases, the total protection time is below the critical tripping time for the ac CB, since the dc-line faults are not metallic and has a value at least several ohms. In some extreme and rare cases when dc lines are metallic short-circuited and the fault point is very close to the dc port of MMC, has a very small value, and the total protection time may exceed the critical tripping time for the ac CB. Therefore, the proposed protection scheme has a wide protection range and can cover most non-permanent dc fault scenarios.

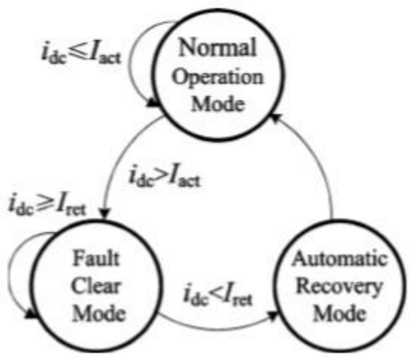

Figure 3.6 Switching of three MMC modes.

3.7 DC-LINK FAULT PROTECTION SCHEME

A dc-link fault protection scheme for the MMC-HVDC system is designed. In this scheme, three operation modes are defined as follows.

1) Normal operation mode: the MMC-HVDC system normally transmits power, while all thyristor switches are kept off state.

2) Fault clear mode: All IGBTs are blocked and all thyristor switches are switched on. During this period, the dc-link fault current freely decay and the ac grid feeds the ac short circuit through MMC arms.

3) Automatic recovery mode: The gating signals of all thyristor switches are removed and the ac short-circuit currents are cut off after one line frequency period. After the dc-link voltage is rebuilt, all IGBTs are deblocked to make the MMC get restarted and operate in normal operation mode again. The protection procedure mainly concerns the switching of the three modes as demonstrated in Fig. 3.6. The switching of the three modes is controlled by comparing the dc-link current with the activating threshold or there turning threshold. Generally, is set to be two or three times the size of the rated dc-link current. is set to be a little bigger than zero. The dc-link fault can be detected by measuring. As soon as the insulation break down on over headline occurs, increases rapidly. Once exceeds, the protection scheme will force MMC to switch from the normal operation mode to the fault clear mode. By detecting again, the protection scheme can judge whether the dc-link fault current has been cleared and the insulation has been restored or not. Once falls below, MMC enters into the automatic recovery mode and finally returns to the normal operation mode (Xiaoqian Li et al 2013). The dc-link fault current clearance process completes in about and the system automatic recovery process requires one frequency period. Thus, it takes a total time of about for the proposed protection scheme to restart normal power transmission after non-permanent dc-link faults have been detected.

3.8 SUMMARY

This chapter described about the operation and performance characteristics of MMC and various sub modules of MMC.

SIMULATION MODELS AND RESULTS

4.1 INTRODUCTION

PSCAD/EMTDC is high-performance multifunctional software that uses functions for numerical computation, system simulation, and application development. Performance of the modular multilevel converter was shown by using PSCAD/EMTDC.

4.2 SIMULATION MODEL USING SINGLE THYRISTOR SWITCHES AND RESULTS FOR THE SAME

An MMC-HVDC system rated at 300 MVA/ 150 kV was simulated using PSCAD/EMTDC. The simulated system has the same configuration as shown in Fig 3.2, and the parameters of the simulated system are listed in appendices Table I. The single line diagram of MMC-HVDC system is represented in Fig 3.1.

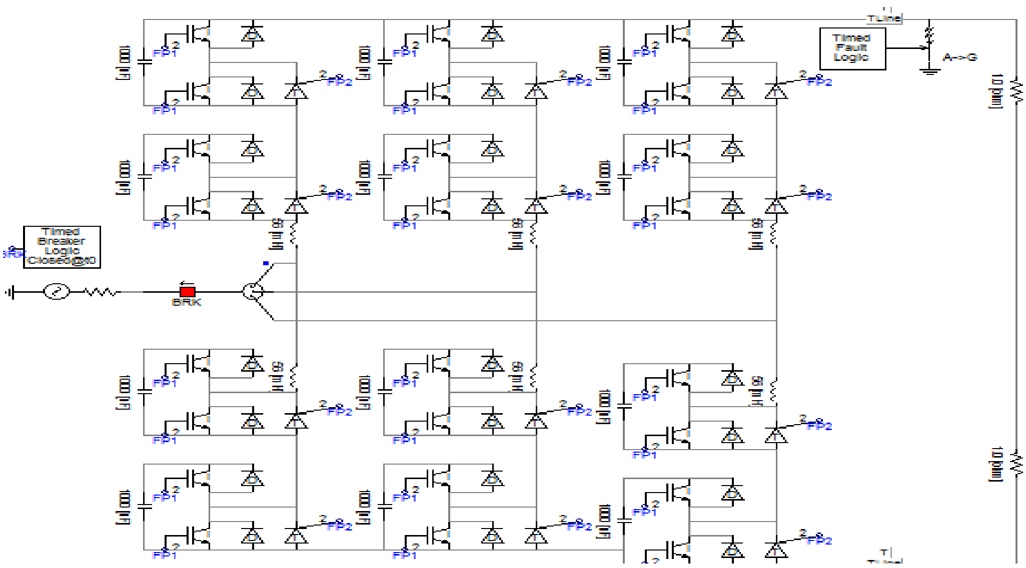

Figure 4.1 Main circuit diagram of MMC using single thyristor switches (PSCAD/EMTDC MODEL)

The firing pulses to the thyristor switches are given by the following diagram.

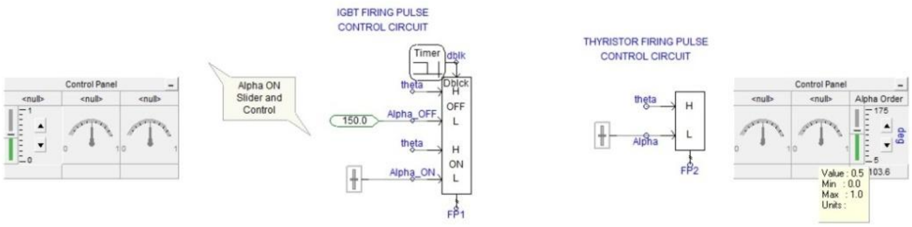

Figure 4.2 firing pulse circuit diagram of MMC (PSCAD/EMTDC model)

In this thesis mainly concerns for a single a unilateral MMC are enough, the dynamic characteristic of MMC when non-permanent dc faults occur is the major focus and the steady-state characteristic, such as harmonic performance, is of less interest. Therefore, an MMC with a low number of levels is employed in the simulation to improve the simulation efficiency. In this section, a five-level MMC is used to verify the effectiveness of the proposed protection scheme.

4.3 SIMULATION RESULTS

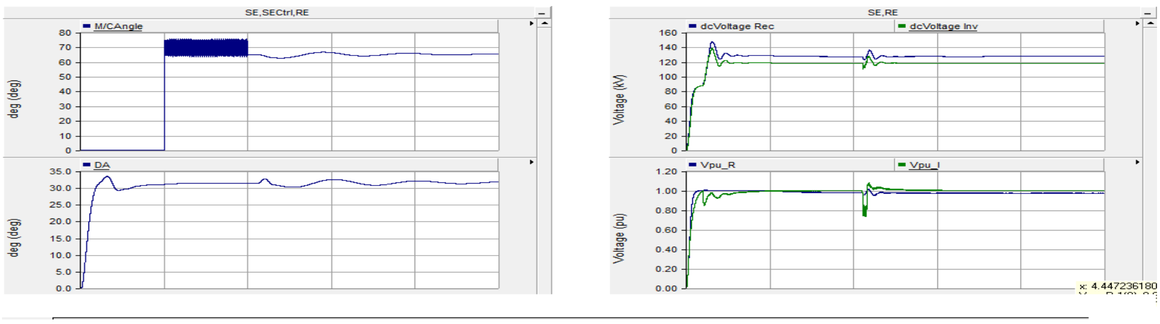

Figure 4.3 simulation results of VSC

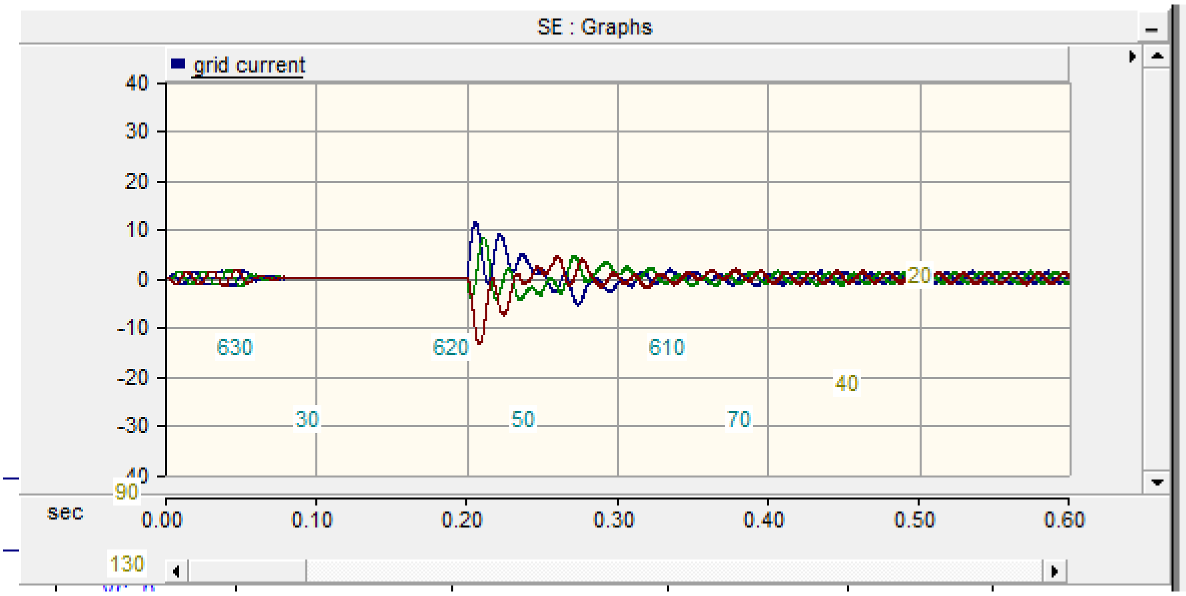

Figure 4.4 ac-grid current

4.3 SUMMARY

This chapter deals with the simulation model of proposed protection scheme and related results.

CONCLUSION

5.1 INTRODUCTION

The detailed models of protection scheme for non-permanent faults on dc overhead lines for the MMC-HVDC system. Simulation results have been verified by employing single thyristor switch.

5.2 WORK DONE FOR PHASE I

The protection scheme for non-permanent faults on dc overhead lines for the MMC-HVDC system by employing single thyristor switch and the results are obtained.

5.3 WORK PLANNING FOR PHASE II

The protection scheme is by employing double thyristor switches and may extend to multi-terminal VSC-HVDC systems. Equipping each MMC with the proposed protection scheme, the fast clearance of non-permanent faults on overhead lines and the quick restart of the entire power transmission may be implemented in a similar way to the two-end MMC-HVDC system.

APPENDIX

TABLE I
PARAMETERS OF THE SIMULATED MMC-HVDC SYSTEM

Parameter	Value
Rated MMC output voltage (RMS)	150kV
Rated capacity of the MMC-HVDC system	300MVA
Rated dc-link voltage of MMC	± 150kV
Rated arm current of MMC (peak value)	1.15 kA
Number of sub-modules of each arm	4
Inductance of each arm	56mH (0.24 pu)
Capacitance of each sub-module	1000uF
On-state resistance of a diode	0.01ohm
On-state resistance of a thyristor	0.005ohm
Resistance of overhead line	0.0917ohm/km
Inductance of overhead line	1.66mH/km

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