Design of Simple Modular Multilevel Converter (MMC) Based- HVDC Transmission System

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Abstract:- **This paper proposes the design of simple Modular Multilevel Converter (MMC)-based High Voltage Direct Current (HVDC) transmission system with a Zig-Zag transformer to provide an artificial neutral point that keeps the voltage level balanced between positive and negative poles of the MMC-HVDC system. A Nearest Level Control(NLC) strategy has been proposed in order to control the gate pulse and the working of the system has been analyzed using a MATLAB/SIMULINK software.**

Keyword: Modular Multilevel Converter, Zig-Zag transformer, Positive and Negative poles and Nearest Level Control.

I. INTRODUCTION

The growth of power-electronic and controllable devices in power systems is rapidly expanding the field of applications for Voltage-Source-Converter (VSC)-based HVDC systems. It is mainly due to the advantages of the present VSC–HVDC systems in comparison with olden day's Line-Commutated Converter (LCC)-based HVDC transmission systems. HVDC system with VSC is a combination power electronic converter along with dc cables and filters to transmit power at higher efficiency.

VSC converters are generally based on Insulated-Gate Bipolar Transistors (IGBT) which is combined along with PWM techniques in order to achieve independent control of active and reactive powers by maintaining the voltage and frequency level at stable range. The output ac waveform in a VSC system is always determined through the topology of the converter. The various topologies that can be used for the dc power transmission are: two-level, Multilevel Neutral-Point Diode-Clamped (NPC), and Multilevel Floating Capacitor(FC), the further multilevel topologies that are developed for industrial medium-voltage applications are the hybrid multilevel converters and the cascaded multilevel.

Trends on converters for HVDC systems include Modular Multilevel Converter(MMC) which is capable of connecting two-level converter modules in cascade connection to achieve the desired ac voltage at the output terminal. MMC topologies use a smaller level switching frequency in order to reduce the converter losses. Further the requirements of filters are not necessary due to the ability to increase the number of levels per phase. The higher output voltage level can be easily achieved and the reliability of the system can be easily improved by increasing the number of Sub-Modules (SMs).

An MMC-HVDC transmission system, when an unbalanced voltage arises between the positive and negative poles, the unbalanced voltage in the line continues to exist in an ungrounded MMC-HVDC transmission system. So to keep the MMC-HVDC at safe operating condition, a zero potential point must be created to control the unbalanced voltage and protect systems from damage.

The grounding device which provides the zero potential point can be installed either on the ac side or at the dc side. Whereas in dc side, we can use a high-resistance grounding device. However, it leads to arise of some drawbacks like high power loss, high cost and low reliability. By considering the above mentioned drawbacks the grounding device can be installed on the ac side would be a better choice.

II. THE MODULAR MULTILEVEL CONVERTER (MMC)

The design of a MMC is shown in Fig. 1 [a].The converter in this context consists of six converter legs, whereas the individual converter legs consist of a series connection of so called Sub-Modules (SMs) connected in series with one converter reactor. Each of the Sub-Modules contains IGBT-half bridge as a switching element and a DC storage capacitor.

As shown in Fig.1, each sub-module is a two-terminal component which can be switched between a state with full module voltage (T_1 = ON, T_2 = OFF) and a state with zero module voltage (T_1 = OFF, T_2 = ON) in both current directions. Next to auxiliary components and electronics, each sub-module is made up of an IGBT of half bridge with a capacitor unit. The capacitor voltage of each sub-module is subject to monitoring and control. The Sub-module section shown in Fig.1 have two functions

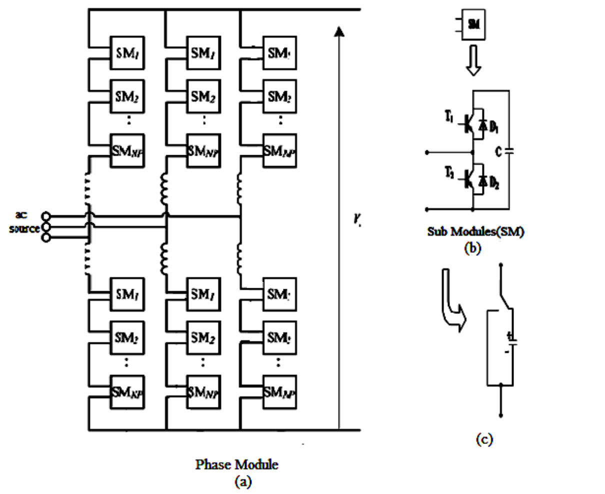


Fig 1: Design of MMC, principle design of a Sub-Modules(SMs) and its electrical equivalent.

The three-phase modules are connected in parallel at the DC side. Since the three generated DC voltages of the phase modules cannot be exactly equal, balancing currents occur between the individual phase units. The capacitor damps these balancing currents to a very low level and make them controllable by means of appropriate methods.

The capacitors substantially reduce the effects of faults arising inside or outside the converter. As a result, unlike in previous VSC topologies, current rise rates of only a few tens of amperes per microsecond are encountered even in so far very critical faults, such as a short circuit between the DC terminals of the converter. These faults are swiftly detected, and, due to the presence of low current rise rates, the IGBTs can be turned off at abnormal experience of current levels. These provide very effective and reliable protection of the system.

III VOLTAGE BALANCING MECHANISM

Generally the Unbalanced voltage between the positive and negative poles occurs offen in the MMC-HVDC transmission system. The various causes for the occurance of the voltage unbalance is: During MMC startup& blocking and control system error, single-phase ground fault as well as on single-pole ground fault and further more. When a pole fault arises, the operation of the MMC will be blocked at once and the MMC-HVDC transmission will be shut down entirely.

As a result, the voltage at the other end of the pole raises doubles from the rated voltage level, and the unbalanced voltage that exists is the most serious problem. So in order to keep the MMC based-HVDC transmission system under safe and with stable operating condition, the unbalanced voltage in the poles must be eliminated sooner. The voltage balance in the poles includes steady-state as well as the startup voltage balance. The steady-state voltage balance is the representation of the grounding device with the feedback mechanism for the unbalanced voltage in the pole in order to keep the transmission system from voltage drift.

The startup voltage balance states that, after the MMC is deblocked, the unbalanced voltage generated in the blocking startup process must be kept balanced effectively by the grounding device. Thus, the grounding device is a efficient solution in order to provide the zero potential point for the MMC-HVDC for safe operation.

The basic structure of the MMC based-HVDC system with grounding device is shown in Fig. 1, which consists of the interface transformer with the dc transmission line, neutral grounding resistor, MMC and the stray capacitance of the dc transmission lines.

Nearest level control (NLC) is a modulation technique used to control the number of sub-modules to turn on in a multi-valve. This modulation technique was chosen for its simplicity and effectiveness. The input of the NLC is the reference voltage waveform. The reference voltage waveform is a sine wave with the amplitude scaled by the modulation index and with phase (δ+θ). The frequency of the reference voltage waveform is 60 Hz. The maximum amplitude of the reference voltage waveform is equal to the maximum peak voltage, Vdc/2 = 100V. The NLC is a quantizer that rounds the reference voltage waveform to the nearest available level according to the nominal capacitor voltage. If the nominal capacitor voltage is 10 V, so the reference voltage waveform is rounded to the nearest value 10n, where n is an integer.

Then the number of sub-modules to turn on in the lower multi-valve is

$$Nlow = \frac{Nsm}{2} + n \quad \ldots\ldots\ldots\ldots (1)$$

And the number of sub modules to turn on in the upper multi-valve is

$$Nup = Nsm - Nlow = \frac{Nsm}{2} - n \quad \ldots\ldots\ldots\ldots (2)$$

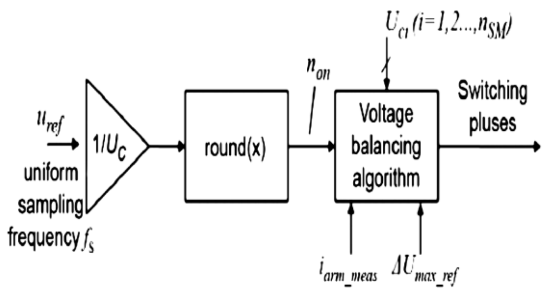


Fig 2: Control diagram of the NLC method.

Due to the conceptual and implementation simplicity of the NLC method, the aim is to use it in converters with a high number of levels. If the number of sub modules is large enough, the harmonics amplitudes and voltage THDs could be reduced to a low range.

IV ZIG-ZAG TRANSFORMER

We can interconnect transformer windings in several ways to produce various output voltages. For power and distribution, we employ the conventional delta or wye connection. But for special applications, we can use another lesser-known configuration: the zig-zag connection. Due to its constructional ability, a zig-zag transformer is more effective for grounding purposes because it has less internal winding impedance going to the ground than when using a wye-type transformer.

In ungrounded systems, it is necessary in order to detect the ground fault. With the zigzag transformer, we are able to insert a resistor between the neutral point and the ground in order to limit the ground fault current on the system. Due to this features the zig-zag connection can be used in power systems to trap triplen harmonic (3rd, 9th, 15th, etc.) currents.

By installing the zigzag transformers near loads that produce large triplen harmonic currents the windings of the transformer traps the harmonic currents and prevent them from traveling upstream, where they can produce undesirable effects.

In the MMC based-HVDC system, if the interface transformer is an arrangement Yn/Δ and theΔ –connection is on the MMC side, we can use the transformer to construct the neutral point artificially.

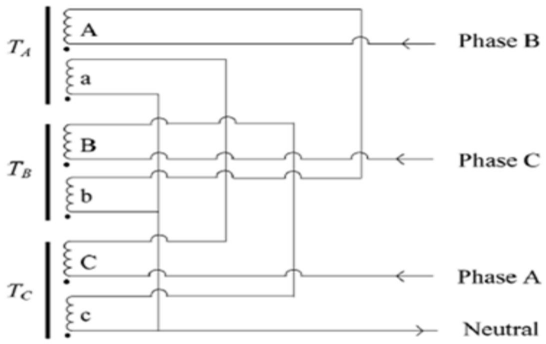


Fig 3:.zig-zag transformer connection

In normal condition of the system, the voltage experienced across the winding of the earthing transformer is √3 times of rated per phase voltage of the system. But during the occurance of single line to ground fault occurs on any phase of the system, zero sequence component of the earth fault current flows in the earth and returns to the electrical power system by way of earth star point of the earthing transformer which can be understood by the phasor diagram of the zig-zag transformer. It gets divided equally in all the three phases.

Hence the currents in the two different halves of two windings in the same limb of the core flow in opposite directions and therefore the magnetic flux set up by these two currents will oppose and neutralize each other. As there is no further increase in the flux due to the presence of fault current.

So it is clear that, the zigzag type earthing or grounding transformer maintains the rated supply voltage at normal current as well as when a solid single line to ground fault current flows through it.

V SIMULATION AND RESULTS

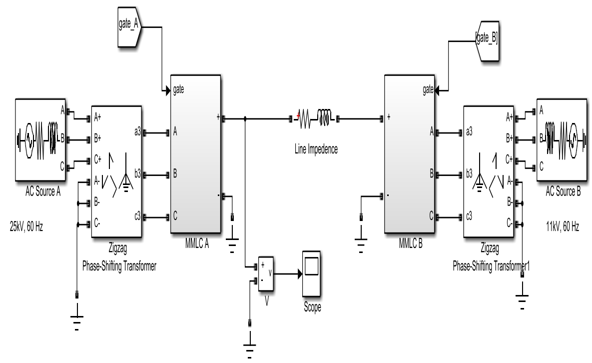


Fig 4: shows the proposed MMC converter system for HVDC transmission system consists of AC source.

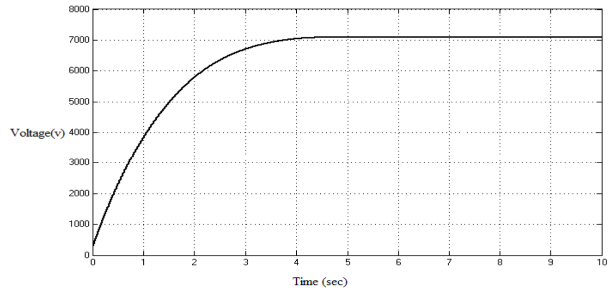
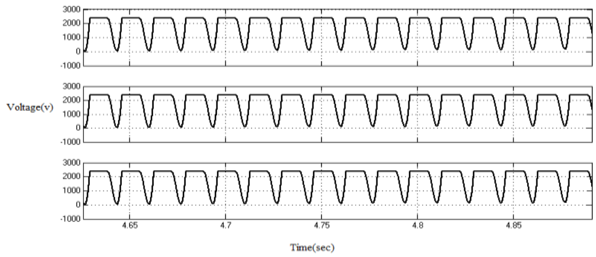
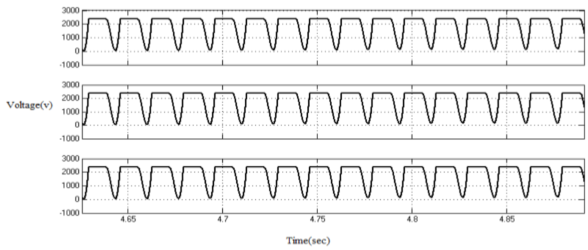


Fig 5: Simulated voltage response of high voltage DC line



(a)



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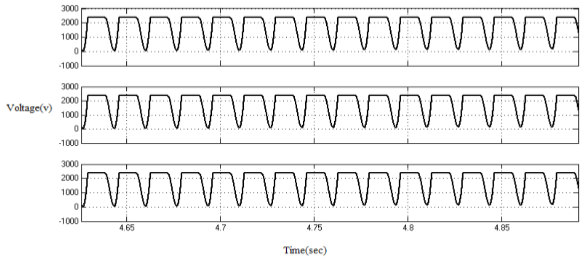
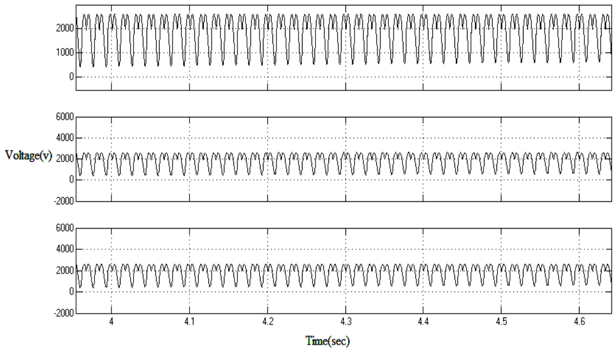
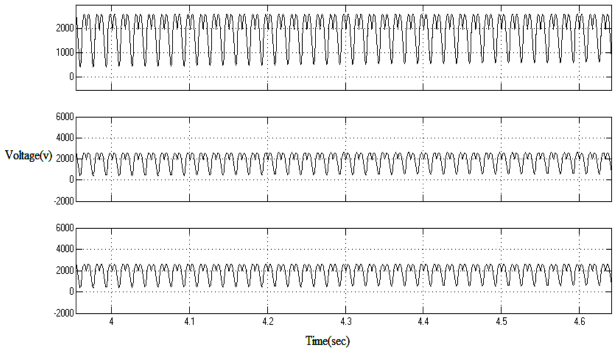


(c)

Fig 6: Simulated capacitor charging and discharging voltage response of upper level sub modules of modular multilevel converter (ac-dc) for phase A shown in (a),for phase B shown in (b) and for phase C shown in (c).



(a)



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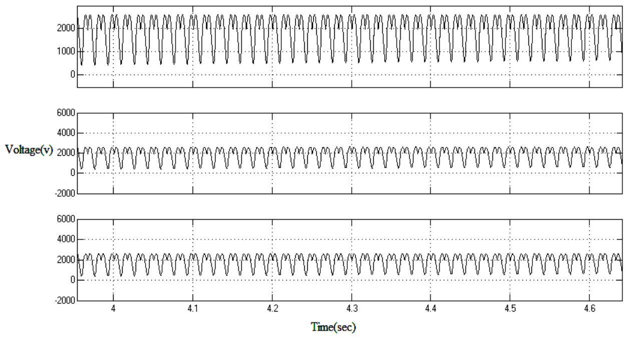

(c)

Fig 7: Simulated capacitor charging and discharging voltage response of upper level sub modules of modular multilevel converter (dc-ac) for phase A is shown in (a) , for phase B its shown in (b) and for phase C its shown in (c).

VI CONCLUSION

The simulation results show that the grounding system consisting of the zig-zag transformer and neutral grounding resistor can keep voltage balance on the dc side of the MMC. And the two-terminal MMC-HVDC transmission system only needed a set of grounding system, which can be installed at either the receiving terminal or the sending terminal. Accordingly, for the interface transformer with the connection on the MMC, the zig-zag transformer may be a preferred solution for the voltage balance between the positive and negative poles of the MMC- HVDC transmission system. Simulation is carried out with the help of MATLAB/SIMULINK.

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