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A NOVEL APPROACH FOR MODULAR MULTILEVEL CONVERTER WITH IMPACT OF VOLTAGE-BALANCING CONTROL ON SWITCHING FREQUENCY

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Abstract— The modular multilevel converter (MMC) was first introduced by Marquart and Lesnicar, It has a modular structure with series connection of power electronics building blocks.MMC possesses a nondeterministic switching pattern and its switching frequency is no longer an independent parameter. This project theoretically investigates how voltage-balancing control influences the switching frequency in the MMC. Equations describing the relationship between the submodule capacitor unbalanced voltage and converter switching frequency are derived. Since unbalanced voltage also impacts the submodule capacitor ripple voltage and voltage/current harmonics, the design interaction between switching frequency and submodule capacitance, as well as the selection of unbalanced voltage are further investigated.

I. INTRODUCTION

This project develops an analytical relationship between the switching frequency and the maximum unbalanced voltage for MMC. The modified sorting method with an unbalanced capacitor voltage threshold in is considered. With the analytical relationship, the switching frequency can be indirectly determined by the unbalanced capacitor voltage threshold. Also this relationship can facilitate the threshold voltage selection. In MMC, the capacitor voltage ripple includes local ripple and average ripple. The local ripple is the unbalanced voltage of that submodule, and the average ripple is caused by the current flowing through the submodules in that arm. Average capacitor voltage ripple does not depend on the switching frequency and is a constant equal to the voltage ripple that would be achieved with an infinite switching frequency. By combining the expression for average ripple in and the derived relationship in this project, the interdependence between the switching frequency and capacitor voltage ripple is explained. This relationship can then be used for switching frequency and submodule capacitance design.The MMC is mainly suitable for high-voltage high-power applications, such as high-voltage direct current (HVDC) transmission systems. Compared with the traditional two-level converter and three-level neutral-point diode-clamped converter, which were originally employed in these applications, the MMC has the following advantages as described in: 1) no direct series of power switches; 2) higher efficiency; 3) less or no need for ac filters; and 4) distributed locations of capacitive energy storages. Even with the drawbacks such as the increased control complexity, higher installed semiconductor power and larger capacitor need, the MMC still becomes the preferred voltage source converter (VSC) topology in HVDC applications due to its overwhelming advantages. Efficiency improvement is one of the most important advantages. By adopting the MMC topology, ABB's newest generation of the HVDC light

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reduces the loss from 1.8% to around 1%, which is a huge improvement for a several-hundred MVA system. The improved efficiency is mostly attributed to the converter's multilevel structure, which allows the power devices to switch at a lower frequency and still maintain acceptable ac sinusoidal waveforms. Switching frequency is an important parameter for power converter design and operation. However, it is not an independent parameter in MMC due to the voltage-balancing controlAs the name implies, voltage-balancing control is employed to balance the submodule capacitor voltages. It manipulates the currents flowing into the different submodule capacitors to achieve balanced voltages, by adjusting the inserting instant and duration for each submodule. The converter switching frequency, defined as the average of all submodule switching frequencies, is thus related to the voltage-balancing control method. Therefore, MMC exhibits a nondeterministic switching pattern. Several works have evaluated the impact of voltage-balancing control on switching frequency. Some voltage-balancing control methods are found to be inefficient in terms of the switching frequency utilization, such as the traditional sorting method in. Alternative methods achieving lower switching frequency are proposed. It is also found that the switching frequency is related to the execution frequency of the voltage-balancing control. On the other hand, the execution frequency also determines the effectiveness of the voltage-balancing control, which can be represented by the unbalanced voltage of submodule capacitors.

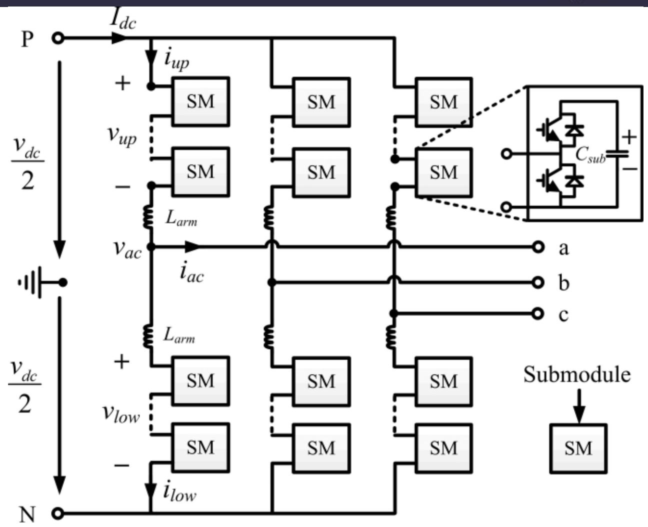

Fig. 1 Basic structure of the MMC with half-bridge submodule

II.HVDC TRANSMISSION SYSTEM

Over long distances bulk power transfer can be carried out by a high voltage direct current (HVDC) connection cheaper than by a long distance AC transmission line**.** **HVDC** transmission can also be used where an AC transmission scheme could not (e.g. through very long cables or across borders where the two AC systems are not synchronized or operating at the same frequency). However, in order to achieve these long distance transmission links, power convertor equipment is required, which is a possible point of failure and any interruption in delivered power can be costly. It is therefore of critical importance to design a HVDC scheme for a given availability.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 transmission lines or underground/submarine cables. It can also be used to interconnect asynchronous power systems

III.LIMITATIONS

The amount of power that can be sent over a transmission line is limited. The origins of the limits vary depending on the length of the line. For a short line, the heating of conductors due to line losses sets a "**Thermal**" limit. If too much

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current is drawn, conductors may sag too close to the ground, or conductors and equipment may be damaged by overheating. For intermediate-length lines on the order of 100 km (60 miles), the limit is set by the voltage drop in the line. For longer AC lines, system stability sets the limit to the power that can be transferred. Approximately, the power flowing over an AC line is proportional to the sine of the phase angle between the receiving and transmitting ends. Since this angle varies depending on system loading and generation, it is undesirable for the angle to approach 90 degrees. Very approximately, the allowable product of line length and maximum load is proportional to the square of the system voltage. Series capacitors or phase-shifting transformers are used on long lines to improve stability. High-voltage direct current lines are restricted only by thermal and voltage drop limits, since the phase angle is not material to their operation.

Classification of Transmission Lines

A Transmission line is a set of conductors being run from one place to another supported on transmission towers. Such lines, therefore, have four distributed parameters,

- **Series Resistance,**
- **Inductance,**
- **Shunt Capacitance &**
- **Conductance**

The voltages and currents vary harmonically along the line with respect to the distance of the point under consideration. This observation is very important in representing the lines of different lengths. It is to be noted that the electrical power is being transmitted over the overhead lines at approximately the speed of light. In order to get one full wave variation of voltage or current on the line has length of the line for 50Hz supply will be given by

$$f.\lambda=v \quad \ldots\ldots\ldots\ldots\ldots \quad (1.1)$$

Where f is frequency of supply, λ is the wavelength i.e., the length of the line in this case and v and velocity of the wave i.e., the velocity of light. Substituting for f=50 and $v=3\times10^8$ m/sec,

$$\lambda=v/f=3\times10^8/50 = 6\times10^6 \text{ mts} \quad \ldots\ldots\ldots\ldots\ldots \quad (1.2)$$

=6000km.

This means that if the length of the line is 6000km the voltage or current wave at the two ends of the will be as shown in fig(2.1)

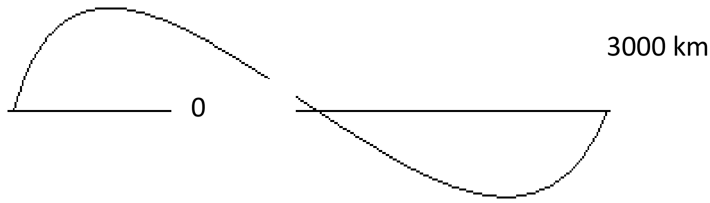

Fig 1.1: Voltage Distribution of 50 Hz Supply

So based on line lengths Transmission lines are classified as

- **Short Transmission Lines**
- **Medium Transmission Lines**
- **Long Transmission Line**

For line lengths less than about 160km, the voltage or current variation on the line is not much and it can be said that for line length of about 160km the parameters could be assumed to be lumped and not distributed. Such lines are electrically short transmission lines. In power system these electrically short transmission lines are again categorized as,

Short Transmission Lines

When the length of the line is less than about 80Km the effect of shunt capacitance and conductance is neglected and the line is designated as a short transmission line. For these lines the operating voltage is less than 20KV.

Medium Transmission Lines

For medium transmission lines the length of the line is in between 80km - 240km and the operating line voltage will be in between 21KV-100KV. In this case, if the shunt capacitance can be assumed to be lumped at the middle of the line is termed as Nominal-T (Or) if the Half of the shunt capacitance is considered to be lumped each end of the line is termed as Nominal- π.

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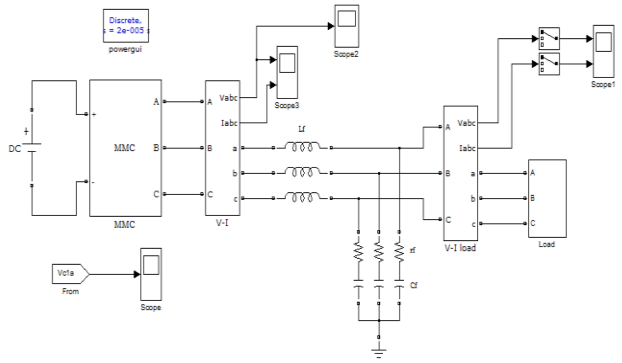
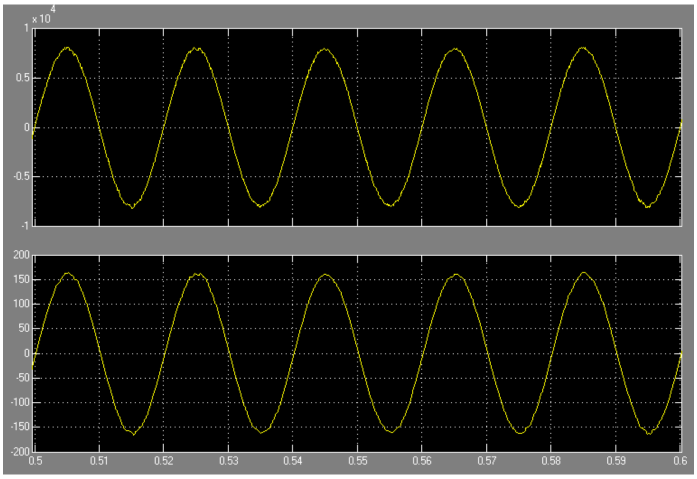
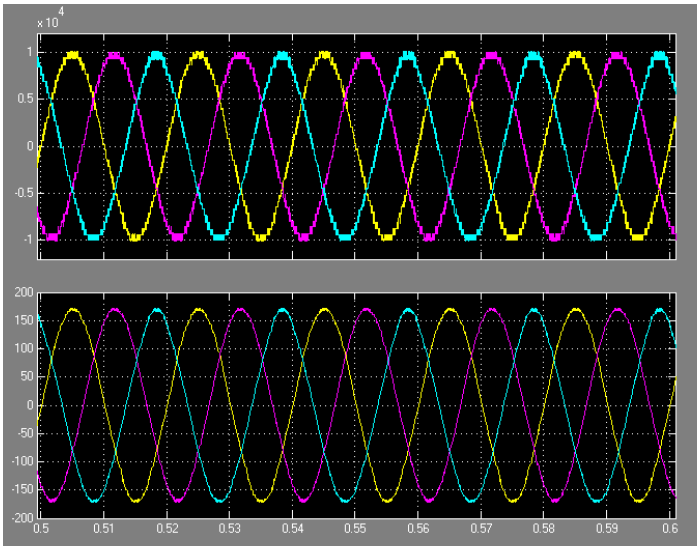
Long Transmission Line

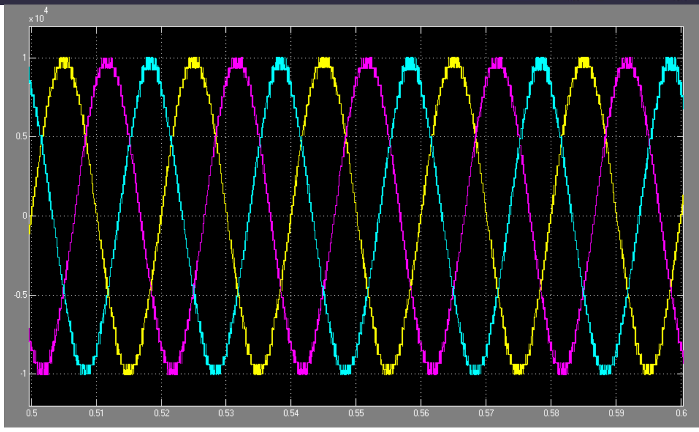
In case the lines are more than 160km long, for accurate solutions the parameters must be taken as distributed uniformly along the length as a result of which the voltages and currents will vary from point to point on the line.

IV. SIMULATION RESULTS









CONCLUSION

This project evaluates the impact of voltage-balancing control on the average switching frequency of the MMC. The analytical relationship between the switching frequency and submodule capacitor unbalanced voltage is derived, for the modified sorting method with an unbalanced capacitor voltage threshold. A key of the derivation is considering voltage-balancing control as a compensation for the arm voltage error. This understanding is also beneficial for how to select voltage-balancing control methods. The derived analytical relationship is very useful for the converter design. It helps to obtain the expression of submodule capacitor voltage ripple, as a function of submodule capacitance and switching frequency. So the submodule capacitance can be selected if providing the voltage ripple and switching frequency requirements. The relationship can also be used for unbalanced capacitor voltage threshold selection, given the design specifications of the switching frequency and submodule voltage rating.

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