Effective Governing of Circulating Current in Modular Multilevel Converter using SVPWM

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Abstract— The Modular Multilevel Converter is another arrangement in the field of medium and high power electronics. The working operation of converter is depending on modular approach. The circulating current which affects both the arms are compensated by the half and full bridges integrated as a proposed approach in this work which comprises of modules, every one being a half-bridge associated in parallel to a capacitor. The fundamental characteristics behind this idea are that it is conceivable to construct the sinusoidal waveform of the voltage by including a few modules in arrangement in each phase leg of the converter. An arm inductance is associated in arrangement with the modules of each arm. As opposed to the two level voltage source converter, where the yield phase voltage can be either give or take the half of the dc-interface voltage, the MMC with SVPWM can change its yield with steps equivalent to every module capacitor's voltage level.

Key words: MMC, HVDC, VSC, SVPWM

I. Introduction

Power electronics are fundamental components in consumer electronics and clean energy technologies [1]. For today’s high-power applications, multilevel converters are gaining a lot of attention, and are becoming one of the top clean power and emery conversion choices for new topologies and control in industry and academia. Currently, multilevel converters are marketed in standard and altered items that power an extensive variety of uses, for example, compressors, extruders, pumps, fans, pounding factories, moving plants, transports, crushers, impact heater blowers, gas turbine starters, blenders, mine lifts, receptive power compensation, marine impetus, high-voltage coordinate current (HVDC) transmission, hydro pumped storage, wind energy conversion, and railway traction, to name a few. Several well-known companies offer multilevel converters commercially for these applications in the field. The innovation of multilevel converters is already grown to such an extent that they can be viewed as a developed and demonstrated innovation, despite everything they have many associated challenges. These challenges motivate researchers from all over the world to discover new ways to further energy efficiency, reliability, power density, simplicity for, and reduce costs of, multilevel converters, and broaden their application field as they turn out to be more alluring and aggressive than the great topologies.

Multi-Terminal High Voltage Direct Current (HVDC) grids seem to be one of the most viable solutions for massive integration of renewable energy to the power grid, especially for societies with an already highly developed AC Grid. This purported Super Grid will fill in as a cross-country thruway for sustainable power source, [1], taking into account geological smoothing impacts which will limit the disadvantages innate to the irregular way of inexhaustible sources.

The MMC topology allows a smooth and nearly ideal sinusoidal output voltage which requires little or no filtering, when many levels are used. It is able to operate at lower switching frequencies; hence the converter losses are more similar to those of the LCC technology [5]. It presents a modular design which may lead to a reduced production cost and easier maintenance. Moreover, it has high scalability allowing a simple adjustment to the maximum voltage by in-creasing or reducing the number of SMs; and finally it has the ability to continue its operation despite module failure.

II. MMC Topology

The MMC examined in this work comprises of various cascaded modules, every one being a half scaffold associated with a capacitor. A few modules associated in arrangement with an inductance frame a converter arm, as per figure 2.1. Two converter arms frame a phase-leg.

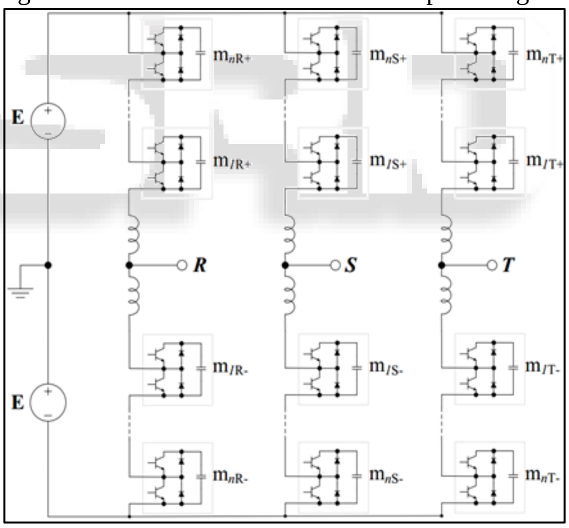

Fig. 1: MMC Topology.

The converter topology is synthesized by connecting several SMs in series to constitute one "multi-valve". Two of these multi-valves are present in each phase, one on the upper part or arm of the converter and one in the lower one, denoted by the sub-indexes u and l respectively. The number of the SMs in series usually depends on the application; however it is possible to generalize the analysis by assuming N.

The structure of the MMC including module capacitors indicates that an inner voltage balancing control for the capacitors’ voltage level is needed. This balancing control includes two parts: the control of the average capacitor voltage in a leg and an individual voltage control for each of the modules in the leg. The dc-link voltage control is assigned to this balancing control. Figure 2.2

provides a general picture of the different controls blocks acting at the MMC.

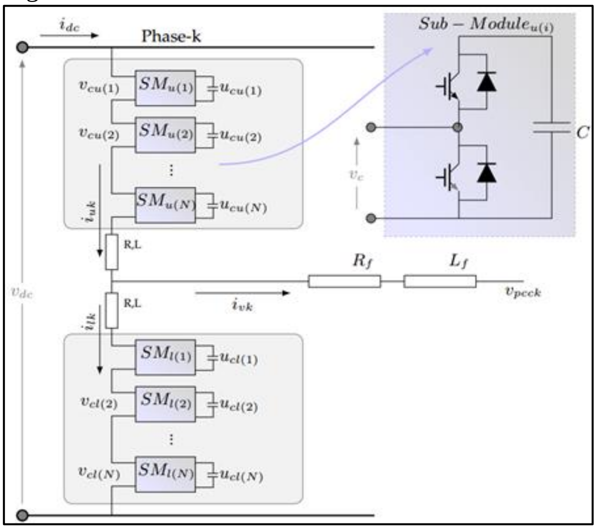

Fig. 2: Topology of a general phase of the modular multilevel converter.

The dc-link capacitors bank and an H-bridge converter that further regulates the voltage applied to the load. The load can be modeled as an inductive-ohmic load. It receives periodically current pulses of trapezoidal shape. The H-bridge together with the magnet is simulated as the total load "seen" by the MMC. The dc- link capacitor is dimensioned to supply and receive the magnet energy and the AFE is rated to compensate for the power losses.

SM's in each arm, equivalent to 2N per phase. An individual SM is formed by a capacitor, IGBTs and their corresponding free-wheel diodes. The two most common SM configurations found in literature are the Half-Bridge (HB) SM and the Full-Bridge (FB) SM.

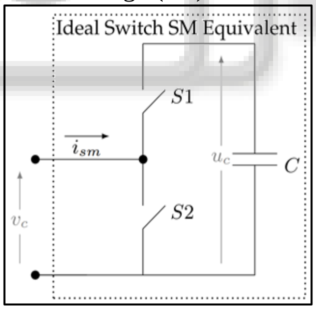

Fig. 3: Ideal Switches SM Equivalent Representation for basic Operation.

The multi-valve formed by the series connection of the N SMs of a single arm is connected to a filter inductor. This will allow for the parallel connection between the DC bus voltage V_{dc} and the voltage output of both arm multi-valves, as the inductor will cope with all voltage differences between them.

III. MMC MODELING

The Modular Multilevel Converter exhibits several topology-specific features, which make its analysis different than conventional power converters.

Initially, the converter branches are characterized by continuous current flow, contrary to the chopped currents of traditional topologies. In addition, a central DC-link capacitor does not exist, since the required storage elements are distributed within the converter branches. This capacitive nature of the phase legs, however, poses challenges in the converter design and operation, especially when the converter faces unbalanced grid conditions. Moreover and unless the sub module capacitance and branch inductance are unrealistically high, so-called circulating currents are expected to flow within the parallel-connected phase legs if the capacitor voltage ripples are not compensated for on a control or hardware level. Finally, the inversely proportional relation between the line current frequency and the sub module capacitor voltage ripples implies an impediment in the case of an MMC low output frequency operation, such as during motor drive startup or low-speed operation.

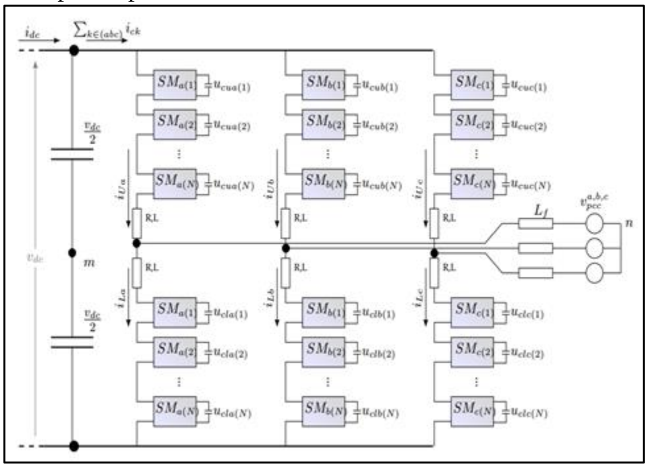

Fig. 4: Topology of a grid connected three phase modular multilevel converter.

The aforementioned specificities require special attention for the comprehension of such a system's physical behavior and the development of converter control systems. The control problem of an MMC system features several sub-problems regarding the external converter magnitudes as well as inner converter quantities.

IV. MMC DESIGN AND CONTROL

The conceptual background of the MMC comes back to the two-level voltage source converter when there are top and bottom switches in each arm of the converter. The problem with the two-level converter in medium and high power applications is extremely high converter switching losses, as achieving a desirable harmonic content in the converter, requires a high switching frequency. Therefore, there needs to be an alternative converter that provides lower switching losses while achieving high voltage ratios. Figure 3.1 shows how the modular multilevel converter idea first developed.

By replacing the single switch or series connected switches, which normally is an insulated-gate bipolar transistor (IGBT) with a series of single-phase two-level converters sub-modules where each SM can be typically realized by the half-bridge converter, the MMC topology was formed.

By employing a series of connected half-bridge cells, the switching frequency associated with the converter can be reduced significantly - to frequencies around the line frequency. Figure 4 illustrates the single phase voltage waveform in the two level voltage source converter versus the voltage waveform in the realized multilevel level converter in the two levels VSC. Using this knowledge, further topologies can be made by using different circuit topologies as a module in the modular-based multilevel structure. As seen in Figure 4, the modular multilevel converters include two arms per phase, where in each arm several identical sub-modules are connected in series. Conventionally, the topology known as MMC for today's industrial applications consists of series connection of the half-bridge modules in each arm. However, each cell can be a half-bridge, full-bridge, or series of switches (IGBT). Figure 5 shows the possible building blocks of the cell in the MMC that can form different topologies from the basic frame of the MMC.

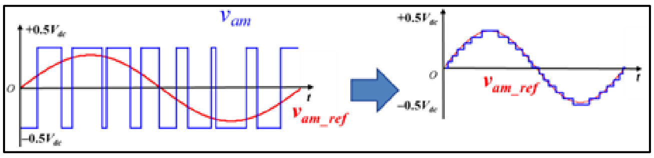

Fig. 5: Voltage waveform in the two-level voltage source and Modular Multilevel Converter.

The half-bridge power cells can only generate positive voltage, while the full bridge modules have the ability to produce the negative voltages as well, as shown in Figure 5. The series connections of the switches can be used either inside the module to generate modules with higher power rates or in series or parallel to generate so called hybrid modular based multilevel converters.

V. Structure of MMC

The neutral point 'o' on the dc side is a fictitious point which divides the dc voltage to two equal parts of 0.5Vdc. The converter topology consists of six phase arms. Each phase has an upper and a lower arm. There are n series-connected modules with an arm inductor in each arm. Each module has two switch devices and a capacitor in a half-bridge structure. In Fig. 6, the output is resistive and there is a neutral point 'm' of the three phases of the load. The n modules per arm can provide n+1 voltage levels.

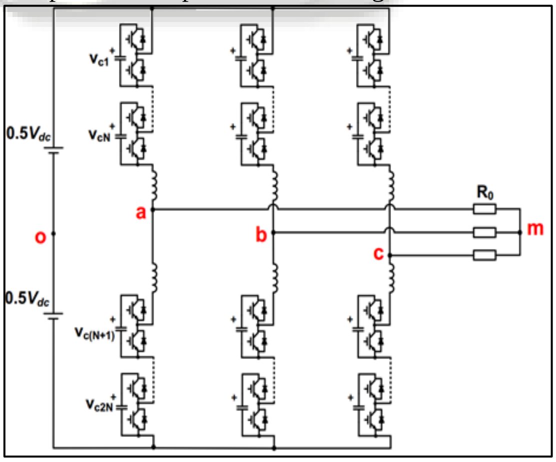

Fig. 6: Three phase MMC System.

VI. Pulse Width Modulation for MMC

The phase-shifted carrier-based PWM (PSC-PWM) method can naturally suppress all low-order harmonics for multilevel converters. The details of the modified PSC-PWM method for one pair modules in upper and lower arm are shown in Fig. 7.

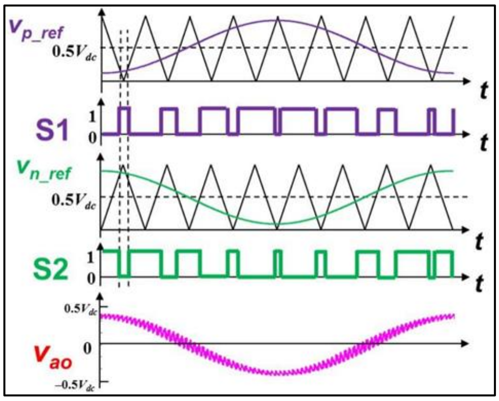

Fig. 7: PWM modulations for MMC with one module per arm.

The reference waveform for upper and lower arm is complementary. Comparing the carrier duty cycle waveform (Vp_ref, Vn_ref) with the triangle wave, the signal state condition of upper and lower module can be achieved. When half-bridge module is used, there are two switching states. The '1' state denotes when the upper switch is "on" and lower switch is "off;" the dc storage capacitor is connected in the phase. The '0' state denotes when the lower switch is "on" and the upper switch is "off." In the "0" state, the capacitor is bypassed from the phase arm. With the state condition of upper and lower module (S1and S2), a sinusoidal output can be generated.

For an MMC with N number of SMs per arm, the reference arm voltages are compared with triangular carriers, each phase shifted by an angle of 360 degrees/N. As shown in Fig. 8 Compare with the same arm duty cycle wave, each module achieve their own switch state condition. Furthermore, in N modules per arm MMC, the output voltage has N+1 level. With 120 degrees' phase shift on reference wave, this modulation method can be extended to three phase's system.

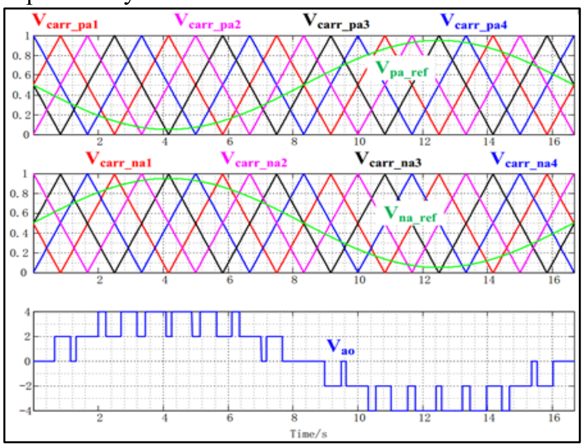

Fig. 8: PWM for multi modules per arm MMC.

VII. Methodology

The use of the half bridge module at the MMC does not offer the possibility to limit dc-link fault currents due to the freewheeling diodes in parallel to the switches. The arm inductance plays the role of the current rise rate limiter but in high current applications, the inductance value is restricted because it causes large voltage drops and reactive power consumption.

In the proposed system of single cell converter, the upper arm is situated between two terminals positive DC and AC. both upper and lower arm consists of N number of half bridges or cells (Ncell) for circuit protection and smoothening of current it is noticeable that Ncell is different from the number of cell levels of converter. The arm inductor reduces the amount of circulating current in circuit at also reduces the effect of harmonics and potential faulty current either inside or outside the circuit. The DC is controlled by cells work as an on/off switch between the upper and lower arms.

VIII. HARMONIC REDUCTION

The capacitor voltage and AC current waveform in kA, upper arm current, circulating current, and upper arm energy is illustrated the following waveforms as shown in figure 9 and 10.

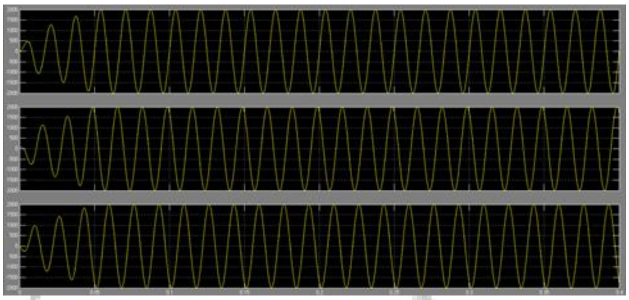

Fig. 9: System Current waveform after controlling of harmonics

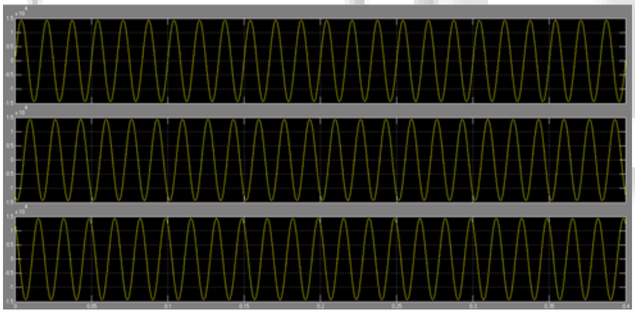

Fig. 10: System Voltage waveform after controlling of harmonics

It is clearly shown from the above results that, the half and full bridge efficiently reduce the effect of injected second order harmonics by circulating current and compensates the reactive power capability of MMC system. The approach utilizes the full and half bridge hybrid multi-level structure to control the circulating current harmonics and SVPWM controlling mechanism in upper and lower arm for remaining distortions presents in the system.

IX. CONCLUSION

The main limitations of the two level converters is its high switching losses due to relatively high switching frequency which necessitates high insulation requirements of the transformer, as well as filters. The use of modular multilevel converters overcomes many of the aforementioned shortcomings, but at the expense of twice as many semi-conducting devices and a large distributed capacitor for each sub module. The principle idea of the hybrid VSC-HVDC, as used in HVDC Max Sine developed by Alstom, is to utilize a two level converter as the fundamental exchanging part with low exchanging frequency and a MMC to give a voltage wave molding capacity on the AC side keeping in mind the end goal to remove the harmonics. The half and full bridge efficiently reduce the effect of injected second order harmonics by circulating current and compensates the reactive power capability of MMC system.

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