Comparison of Harmonics and Common Mode Voltage in NPC and FLC Multilevel Converters

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Abstract — Three-level converters are widely utilized by industries thanks to the advantages of less \( dv/dt \) and less frequency common mode voltage in comparison to conventional two-level PWM inverters. Since these converters utilize switches as fully on or fully off elements and they feed a floating output system, common mode voltage will be unavoidable. This paper presents a comprehensive analysis of common mode voltage in NPC and FLC Multilevel converters using different structures of sine-triangle pulse-width-modulation schemes. Simulations have been performed in Matlab/Simulink® environment.

Keywords — Electrical Drive, Harmonics, High Voltage Power Converter, Multilevel Converters

I. INTRODUCTION

Multilevel converters have found a wide acceptability in medium and high voltage applications thanks to the advantages of less distortion in the output voltages and easier connection of semiconductor devices in series/parallel [1-2]. However, multilevel converters have generated some unexpected problems, when they are used in electric drives, such as motor bearing currents due to common mode voltages which result in bearing damage. Isolation of the stator winding in medium voltage motor is not so high in comparison to low voltage motors. Therefore, generating less \( dv/dt \) in the converter output leads to less isolation level within the motor. Conventional two-level and multilevel inverters have been found to be a very important source of bearing failures, originated by high \( dv/dt \) in the motor voltages [5]. Common-mode voltages are generated by both rectification and inversion processes and they are dependent on the topology of the rectifier, inverter and the modulation scheme which is used for inversion process. This paper will compare the common mode voltage in three-level neutral point clamped (NPC) and flying capacitor (FLC) multilevel converters using different SPWM methods, assuming the rectifier topology is unchanged. It is organized in 2 parts: part 1 deals with common mode voltage in NPC converter and part 2 with FLC converter. The results will be compared in the conclusion.

II. COMMON MODE VOLTAGE IN MULTILEVEL CONVERTERS

Fig. 1 shows a generic block diagram of VSI fed drive. The rectification and inversion process leads to a zero-sequence voltage which will be applied to the motor. This common mode voltage can appear on motor windings, leading to shaft currents and damage the winding insulation.

So, when the motor is fed by a PWM inverter, it is subjected to imbalance voltages between phases instantaneously. The zero sequence voltage appeared on the generator neutral point with respect to ground creates bearing currents. The amplitude of this zero sequence voltage can be easily calculated:

\[
v_n = \frac{v_a + v_b + v_C}{3} = v_{CM}
\]  

(1)

In order to analyze common mode voltage, two different 3-level topologies are assumed in this paper: diode clamped and flying capacitor multilevel converters. For both topologies, different SPWM methods are used to show the effect of modulation scheme on the generated zero sequence voltage.

III. COMMON MODE VOLTAGE IN NPC MULTILEVEL CONVERTER

The concept of the multilevel converter was introduced over 20 years ago by A. Nabae et.al. Considerable research has been done in this area, different modulation scheme have been introduced, each of which has its own advantages and disadvantages. The basic topology of the 3-level multilevel converter is shown in Fig. 2.
To compare the common mode voltage in NPC multilevel converter, in-phase disposition (IPD) and opposite phase disposition (OPD) modulation schemes are investigated. Moreover, level-shifted PWM is also investigated for FLC multilevel converter. Fig. 3 shows the generation of gating signals for each switch in different SPWM methods. The switching states and the output pole voltage are shown in table I. The effect of adding offset is elaborated in each modulation scheme.

From Fig. 3, it is understood that there are two triangular waves which establish the switching frequency of the converter. The reference sinusoidal waves are represented by:

\[ v_c = V_a \sin(\omega t) \]
\[ v_b = V_a \sin(\omega t - \frac{2\pi}{3}) \]
\[ v_c = V_a \sin(\omega t - \frac{4\pi}{3}) \]

(2)

Fig. 4 shows the simulation result for generated common mode voltages when no third-harmonic is injected. The common mode voltage in OPD-PWM has less \( \frac{dv}{dt} \) than that in IPD-PWM. In [3] and [4], the effect of adding offset to modulation waveform has been discussed. The amplitude of common mode voltage for both schemes is the same. Fig. 5 illustrates the common mode voltage, \( V_{og} \), when the third-harmonic has been added to the modulation signals. From the figure, it is clear that by adding the offset, the amplitude of common mode voltage does not change. The only difference is that the inverter common mode voltage, \( V_{cg} \), is less sharp by injecting third-harmonic. This may be advantageous in view of common mode voltage stress on motor winding insulation since less partial discharges may occur, but the motor still needs significant insulation. Fig. 6 shows the common mode voltage when the modulation index is more than unity.

![Fig. 3 generation of pulses for 3-level inverter with (a) IPD (b) IPD with third-harmonic injection (c) OPD with third-harmonic injection (d) PS-PWM with third-harmonic injection](image-url)

Table I switching States of 3-level NPC Converter

<table>
<thead>
<tr>
<th>Device Switching Status</th>
<th>Inverter Terminal voltage ((V_{og}))</th>
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<tbody>
<tr>
<td>on on off off</td>
<td>(V_a) / 2</td>
</tr>
<tr>
<td>off on on off</td>
<td>0</td>
</tr>
<tr>
<td>off off on on</td>
<td>(-V_a ) / 2</td>
</tr>
</tbody>
</table>

One interesting observation is that the amplitude of common mode voltage decreases when modulation index is greater than unity. In this case, the output voltage at the terminal of the inverter has less THD, where at the same time it decreases the amplitude of common mode voltage. This will be discussed in the next section.
IV. COMMON MODE VOLTAGE IN FLC MULTILEVEL CONVERTER

In this part, the NPC multilevel converter is replaced by FLC Multilevel converter. All the components such as source, rectifier, load and capacitors are the same with NPC converter. The only difference between the NPC and FLC multilevel converter is that the diodes in each leg are replaced by a capacitor. The simulation results are shown in Fig. 8. To make a comparison between common mode voltages in NPC and FLC inverters, the same modulation index, 0.9, has been used. For IPD and OPD modulation schemes, the peak of common mode voltage in FLC converter is much higher than that in NPC converter. Although by using phase-shifted modulation scheme in FLC converter, the peak of common mode voltage is the same as those in Fig. 3, but the frequency of the generated common mode voltage increases which is not desirable. Fig. 9 shows the effect of increasing modulation index in FLC multilevel converter. As in the case of NPC converter, the peak and frequency of common mode voltage decreases. The reduction in frequency is greater than that in NPC converter. However, the peak of common mode voltage is larger than that in NPC converter. OPD modulation scheme provides less stress on the motor insulation, since there are less sharp peaks in the common mode voltage.

Fig. 7 FLC multilevel Converter topology

Fig. 8 Common mode voltage in 3-level FLC converter without third-harmonic injection: (a) IPD, (b) OPD, (c) Phase shifted

Fig. 9 CM voltage in 3-level FLC converter when the modulation index is more than unity: (a) IPD, (b) OPD, (c) Phase-shifted
converter generally provides better profile when common mode voltage is of concern.

![Graph](image1)

**Fig. 10** Modulation index versus (a) common mode voltage amplitude and (b) THD in the line-to-line voltage in 3-level NPC Converter

![Graph](image2)

**Fig. 11** Modulation index versus (a) common mode voltage amplitude and (b) THD in the line-to-line voltage in 3-level FLC Converter

Both topologies have the same THD profile, while the amplitude of common mode voltage in NPC converter with modulation index more than unity is less than that in FLC converter. However, for certain applications, it is better to use FLC converter. OPD modulation scheme gives better performance in FLC converter for high modulation indexes. Since both topologies have approximately the same THD profile in the line-to-line output voltage, other important considerations should be taken into account such as generated common mode voltage. The decisive factors for choosing the converter topology and modulation scheme depend on the type of application.

V. CONCLUSION

This paper evaluates harmonics and common mode voltage in 3-level neutral point clamped (NPC) and flying capacitor (FLC) multilevel converters. The harmonic content of the output voltage and the peak amplitude of common mode voltage for each topology under different sinusoidal pulse-width-modulation schemes are analyzed and compared. The simulation results show that the amplitude of common mode voltage depends upon the modulation index and scheme. From the simulation results, it is concluded that NPC 3-level converter has better performance than FLC converter, when generated common mode voltage is of concern.

VI. APPENDIX-I

<table>
<thead>
<tr>
<th>Table II. Simulation Parameters</th>
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<tbody>
<tr>
<td>LOAD VOLTAGE</td>
</tr>
<tr>
<td>Load Power</td>
</tr>
<tr>
<td>Filter Inductance</td>
</tr>
<tr>
<td>DC Link Voltage</td>
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<tr>
<td>Carrier Frequency</td>
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VII. REFERENCES


