

# Electrolytic Capacitor Ripple Current Analysis of SPWM NPC Three-Level Inverter

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**Abstract**—Neutral point clamped (NPC) three level inverter is widely used in high voltage and high power applications. The capacitance of DC bus plays an important role in the inverter. The DC capacitor current and neutral point current affect the lifetime of the electrolytic capacitor. The equivalent circuit model of electrolytic capacitor and the analytical expression of ripple current are analyzed in this paper. Finally, the validity of the expression is verified with simulation in MATLAB/Simulink.

**Keywords**—three-level inverter; Pulse Width Modulation (PWM); electrolytic capacitor; ripple current; reliability

## I. INTRODUCTION

Electrolytic capacitors have been widely used in power electronics system because of the features of large capacitance, small size, high-voltage, and low-cost. An electrolytic capacitor provides a low impedance path for the ac current and acts as a constant voltage source in the power converters. Unfortunately, it is reported that the electrolytic capacitors are responsible for the failure of power electronics system in 60% of the cases[1]. In order to ensure the DC voltage stability of the converter, the DC-Link capacitor is connected at the DC side to absorb the high amplitude pulsating current. But the DC bus ripple current can cause capacitance heating, and the neutral point current can cause unbalance voltage between two capacitor banks.

In this paper, the NPC three-level inverter is studied, and the failure mechanism and equivalent circuit model of electrolytic capacitor are introduced. The capacitive current ( $i_{DC}$ ) and neutral point current ( $i_{NP}$ ) of DC bus under Sinusoidal Pulse Width Modulation (SPWM) mode are analyzed. All simulations have been developed with the Matlab SimPowerSystems Blockset.

## II. FAILURE MECHANISM OF ALUMINUM ELECTROLYTIC CAPACITOR

The DC side capacitor plays an important role in the NPC three-level inverter. The two capacitor parts having a voltage regulation divide the DC side voltage into three levels. The capacitor can also balance the instantaneous power difference between the input source and output load, and minimize voltage variation in the DC link. In some applications, they are also used to provide sufficient energy during the hold-up time. Therefore, the capacitor is critical for the NPC three level inverter.

The aluminum electrolytic capacitor is composed of a capacitor core, a protective structure and a lead out terminal, where in the most important component is the capacitor core, and the structure is shown in Fig. 1.

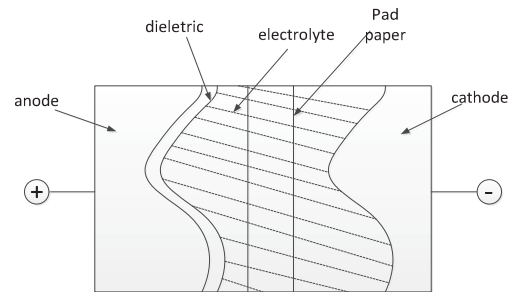


Fig. 1. Structure diagram of aluminum electrolytic capacitor core

According to the physical structure, a simplified equivalent circuit of the aluminum electrolytic capacitor can be obtained, as shown in Fig. 2. Where  $C$  is the capacitance component,  $R_C$  is the series equivalent resistance of the capacitor,  $R_L$  is the leakage resistance of the capacitor,  $R_D$  and  $C_D$  are the parasitic resistance and parasitic capacitance of the capacitor,  $ESL$  is equivalent series inductance.

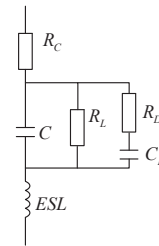


Fig. 2. Simplified equivalent circuit of aluminum electrolytic capacitor

In practice, the electrolytic capacitor in use will experience, continuous evaporation of electrolyte, and the key lifetime parameters of electrolytic capacitor (electrostatic capacity, equivalent series resistance and leakage current) and appearance will change. The evaporation rate of the electrolyte increases with the increase of the capacitance temperature, which leads to the increase of the equivalent resistance of the capacitor and the decrease of the capacitance. The temperature

of the capacitor plays an important role in the failure of the aluminum electrolytic capacitor. However the temperature of the capacitor is affected by the ambient temperature and the rise of internal temperature caused by the ripple current of the capacitor body. Power losses are a function of the capacitor current and its series equivalent resistance. Power losses will cause heating within the capacitor are defined as in(1).

$$Q = I^2 R t \quad (1)$$

Where  $Q$  is power losses,  $I$  is ripple current,  $R$  is equivalent series resistance and  $t$  is the time of ripple current flowing through capacitor.

In the NPC three-level converter, the neutral point current  $i_{NP}$ , which leads to lower transmission power capacitor on the DC bus imbalance, is caused by neutral point voltage fluctuation. So the voltage between the two capacitors is imbalanced, which certainly reduces the reliability of capacitor.

### III. ANALYTIC EXPRESSION OF RIPPLE CURRENT

#### A. Analytical formula of DC bus ripple current

Ripple current is the alternating current flowing through a capacitor, which causes capacitor to heat up. The maximum allowable ripple current of capacitor is affected by environment temperature, capacitor surface temperature, radiating area, loss angle, AC frequency and so on. The main circuit of a three-phase, three-level NPC inverter is show in Fig. 3. Each of the IGBT and the freewheeling diode module is considered as a switch, which accepts the corresponding phase current and flows through the half bridge arm of the inverter. The sum of phase currents of inverter leg is represented by  $i_1$ . The DC component in the current  $i_1$  is supplied by the DC power supply, while the AC component is supplied by the DC side capacitor.

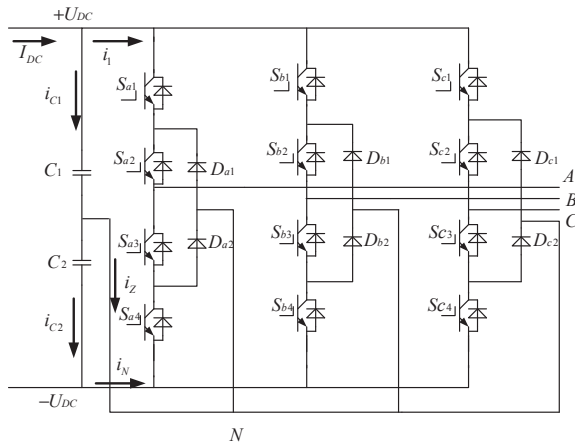


Fig. 3. Topology of NPC three-level converter

The schematic diagram of the carrier and modulation wave signals of NPC three-level converter is show in Fig. 4, the carrier phase modulation is adopted in the modulation mode. Fig. 4 shows the intervals, or sectors, in which the three reference voltage signs are constant.

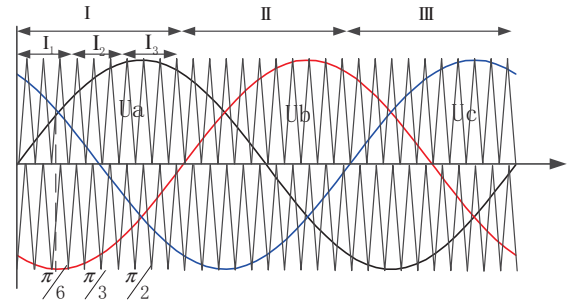


Fig. 4. Traditional carrier sinusoidal PWM modulation

This paper is based on the following two assumption:(a).the output currents are sinusoidal, and the DC-link voltage is constant; and (b).sinusoidal output currents imply that the switching frequency ripple content of the phase current is negligible. On the basis of the above two assumptions, the three-phase output current of the inverter can be considered as (2):

$$\begin{cases} i_A = I_N \sin(\theta - \phi) \\ i_B = I_N \sin(\theta - \frac{2}{3}\pi - \phi) \\ i_C = I_N \sin(\theta + \frac{2}{3}\pi - \phi) \end{cases} \quad (2)$$

In (2),  $I_N$  is the load current amplitude, and  $\phi$  is the load power factor angle.

The DC side input current  $i_1$  is the total current flowing through the switch, which can be calculated as (3) and expressed as the output current and the switching state of the switch.

$$i_1 = S_{Ta1} \cdot i_A + S_{Tb1} \cdot i_B + S_{Tc1} \cdot i_C \quad (3)$$

Here,  $S_{Ta1}$ ,  $S_{Tb1}$ , and  $S_{Tc1}$  are switching functions, with 1 for turn-on and 0 for turn off.

As shown in Fig. 4, the reference modulate signal is symmetrical, and the magnitude and variation of the input current are exactly the same within the  $\frac{2}{3}\pi$  range. The difference is in the switch status of each bridge arm. The reference voltage is divided into three intervals as shown in Fig.4, and only the average and effective values of  $i_1$  in the interval I are calculated. For interval I of interval I<sub>1</sub>, the following rules are made: all switches  $S_{Ta1}$ ,  $S_{Tb1}$  and  $S_{Tc1}$  are switched off during  $T_0$ ; Only switch  $S_{Ta1}$  is switched on during the  $T_1$  period; during  $T_2$ , the switches  $S_{Ta1}$  and  $S_{Tc1}$  are switched on. The duty cycle can be calculated as in (4)~(6).

$$T_0 = \frac{T_s}{2} [1 - M \sin(\theta + \frac{2}{3}\pi)] \quad (4)$$

$$T_1 = \frac{T_s}{2} M [\sin(\theta + \frac{2}{3}\pi) - \sin(\theta)] \quad (5)$$

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