Dual Pulse Width Modulation Harmonic Suppression Technology of H-bridge DC Converter

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Abstract. In order to solve the H-bridge DC converter under the traditional pulse width modulation the peak value of EMI is mainly distributed at the switching multiple frequency, and the serious electromagnetic interference. This paper introduces dual pulse width modulation harmonic suppression technology based on the H-bridge DC converter. By expanding the spectral distribution of the harmonics by two pulse widths, the duty cycle and phase of the two pulse widths can be changed to reduce the power of a certain harmonic, and compared with the traditional single pulse width, the analysis of the two pulse width modulation Spectrum distribution on the grid side. The electromagnetic interference under two kinds of pulse width modulation is realized by analyzing through matlab / Simulink software simulation.

1. Introduction

With the continuous development of science and technology, compared to traditional transformer power supplies, due to the advantages of high power conversion efficiency and high power density, more and more digital, high-frequency, high-power power electronics Equipment has been widely used in various fields of national economy and national defense construction, but at the same time, electromagnetic interference caused by the application of power electronic equipment has brought electromagnetic pollution [1].

In the DC power supply network system on ships, a large number of power electronic equipment (such as choppers for motor speed regulation, inverters converted to AC power, etc.) are used, and they may cause large electromagnetic interference. However, for sonar, radar and other vulnerable devices in the same closed metal cabin, the interference may be caused by improper grounding or coupling of impedance to electrical equipment by common impedance, causing serious and prominent electromagnetic compatibility problems [2, 3]. The limited space on submarines and warships, the complex electromagnetic environment, and the effective and safe operation of military equipment require the good EMC (electromagnetic compatibility) performance of each power electronic converter to the DC grid to ensure that the entire DC grid system has good Electromagnetic compatibility, so the EMC requirements of the ship's DC grid are very strict.

Power electronic equipment generates high-order harmonics due to its high-frequency switching action, which increases electromagnetic interference and adversely affects electrical equipment. In order to reduce harmonic interference and improve the electromagnetic compatibility of electrical equipment, filters are usually used to reduce harmonic interference [4, 5]. The use of LC passive filters
is the most traditional and simple method, but its filtering flexibility is poor, and it can only suppress harmonics in a specific range; at the same time, the operating status and impedance of the power grid will interfere with the compensation. Active filters are limited by the withstand voltage and rated current of the original power electronics. The design and manufacturing process is complicated and the cost is extremely high. The increase of the filter will increase the volume of electrical equipment at the same time, which will further improve the limited space of the ship.

This paper studies the research on the dual-pulse width modulation technology of the H-bridge DC converter, and strives to improve the electromagnetic compatibility of the H-H-bridge DC converter, reduce the input-side harmonics of the H-bridge DC converter, and reduce the electromagnetic interference of the DC converter to the DC grid. To reduce the equipment's requirements for filter performance and alleviate other negative effects caused by the installation of complex filtering devices, it has important theoretical and practical significance in military and engineering.

2. H-bridge DC converter

The H-bridge DC converter circuit consists of 4 fully controlled switching devices (T1, T2, T3, T4) and 4 diodes (D1, D2, D3, D4).

![Figure 1. H-bridge DC converter.](image)

The H-bridge DC converter circuit can achieve four-quadrant DC-DC conversion compared with the traditional Buck converter and Boost circuit. According to the direction of the output voltage \(V_o\) and the output current \(i_L\), it can be divided into four quadrant working modes. When the H-bridge DC converter works in the first quadrant, the switch \(T_4\) is placed in the on-state, \(T_3\) is placed in the off-state, \(T_2\) is completely off, and \(T_1\) is periodically switched on and off. It is equivalent to a buck DC converter. The working equivalent circuit is as Figure 2.

![Figure 2. First quadrant operating equivalent circuit.](image)

3. Dual pulse width modulation

3.1. Grid-side current

The control signal of the switch \(T_1\) in the first quadrant operation mode under the dual pulse width modulation is as Figure 3:
There are two pulse width signals with different duty ratios and phase adjustments in one switching cycle. The width of the front pulse width is $T_{on1}$, the duty ratio is $D_{on1}$, and the width of the rear pulse width is $T_{on2}$. The ratio is $D_{on2}$, one switching cycle time is $T$, the total duty cycle $D$ in one switching cycle, and two pulse width acting time intervals $T_{off1}$, $T_{on1}$, $T_{on2}$, $D$, $T_{off1}$, $T_{off2}$ satisfy the following formula (1):

$$
\begin{align*}
T_{on1} &= T \cdot D_{on1} \\
T_{on2} &= T \cdot D_{on2} \\
T_{off1} &= T \cdot m \\
D &= D_{on1} + D_{on2} \\
T &= T_{on1} + T_{on2} + T_{off1} + T_{off2}
\end{align*}
$$

(1)

The working mode of the H-bridge DC converter in the first quadrant under double pulse width modulation can be divided into four time periods according to the switching on and off of the switching device. The switching period $T_{on1}$, $T_{on2}$, and the switching period $T_{off1}$, $T_{off2}$.

When the current of the inductor is always greater than zero during the working cycle, the circuit is said to work in Continuous Current Mode (CCM). During $T_{on1}$ and $T_{on2}$, the switch $T_1$ is turned on and the diode $D_2$ is turned off. $T_1$ in the double-pulse width control signal control circuit is turned on, and the input voltage $V_S$ is applied to both ends of the diode $D_2$ and the output filter inductor $L$ through the switch tube, the output filter capacitor $C$, and the diode $D_2$ is subjected to reverse voltage shutdown. In the circuit, the switching tube operates at a high frequency and the switching cycle is short. Because the values of the filter inductor $L$ and the filter capacitor $C$ are sufficiently large, the voltage ripple of the filter capacitor $C$ is not large during $T_{on1}$ and $T_{on2}$, so the capacitor voltage $V_C$ can be approximated to keep its average value $V_O$ unchanged, so the voltage applied to $L$ during the period is $V_S-V_O$, because the existence of this voltage difference makes the current of the wave filter inductor linearly increase, and the slope is $k_1$. The expression is as follows:

$$
\begin{align*}
\frac{di_L}{dt} &= \frac{V_S - V_O}{L} = \frac{(1-D)}{L} \cdot V_S \\
k_1 &= \frac{di_L}{dt} = \frac{V_S - V_O}{L} = \frac{(1-D)}{L} \cdot V_S
\end{align*}
$$

(2)

During the $T_{off1}$ and $T_{off2}$, the switch $T_1$ is turned off, and $i_L$ continues to circulate through the diode $D_2$. At this time, the voltage applied to $L$ is $-V_O$, $i_L$ decreases linearly, and the slope is $k_2$: 
\[ k_L = \frac{dI_L}{dt} = -\frac{V_o}{L} = -\frac{D}{L}V_S \]  

Therefore, the expressions of the inductor current \( i_L(t) \) and the input-side current \( i_{in}(t) \) in the CCM can be obtained as follows:

\[
\begin{align*}
   i_L(t) &= \left\{ \begin{array}{ll}
   I_{L0} + k_1 t; kT \leq t \leq kT + D_{on1}T \\
   I_{L1} - k_1 (t - D_{on1}T); kT + D_{on1}T \leq t \leq kT + (D_{on1} + m)T \\
   I_{L2} + k_2 (t - D_{on2}T - mT); kT + (D_{on1} + m)T \leq t \leq kT + (D_{on1} + m + D_{on2})T \\
   I_{L3} - k_2 (t - D_{on2}T - mT - D_{on2}T); kT + (D_{on1} + m + D_{on2})T \leq t \leq kT + T \\
\end{array} \right.
\end{align*}
\]

\[
\begin{align*}
   i_{in}(t) &= \left\{ \begin{array}{ll}
   I_{L0} + k_1 t; kT \leq t \leq kT + D_{on1}T \\
   0; kT + D_{on1}T \leq t \leq kT + (D_{on1} + m)T \\
   I_{L2} + k_2 (t - D_{on2}T - mT); kT + (D_{on1} + m)T \leq t \leq kT + (D_{on1} + m + D_{on2})T \\
   0; kT + (D_{on1} + m + D_{on2})T \leq t \leq kT + T \\
\end{array} \right.
\end{align*}
\]

3.2. Harmonic analysis

The Fourier transform of the DC-side current can obtain the content of the DC-side current harmonics and its power spectral density.

\[
i_{in}(t) = I_m + \sum_{n=1}^{\infty} \left( a_n \cos(n\omega t) + b_n \sin(n\omega t) \right)
\]

\[
a_n = \frac{2}{T_s} \int_0^T (i_{L0} + k_1 t) \cos(n\omega t) dt + \int_{T_1}^T (i_{L2} + k_2 t) \cos(n\omega t) dt
\]

\[
= \frac{2}{T_s} k_1 \left[ \frac{1}{n\omega} \left( t \sin(n\omega t_1) + t \sin(n\omega t_2) + t \sin(n\omega t_3) + \frac{1}{n^2 \omega^2} \left( \cos(n\omega t_1) + \cos(n\omega t_2) - \cos(n\omega t_3) - 1 \right) \right) \right]
\]

\[
b_n = \frac{2}{T_s} \int_0^T (i_{L0} + k_1 t) \sin(n\omega t) dt + \int_{T_1}^T (i_{L2} + k_2 t) \sin(n\omega t) dt
\]

\[
= \frac{2}{T_s} k_1 \left[ \frac{1}{n\omega} \left( t \cos(n\omega t_1) + t \cos(n\omega t_2) + t \cos(n\omega t_3) + \frac{1}{n^2 \omega^2} \left( \sin(n\omega t_1) + \sin(n\omega t_2) - \sin(n\omega t_3) \right) \right) \right]
\]

\[
P(i_m) = \frac{1}{T_s} \int_0^T |i_{in}(t)|^2 dt = \sum_{n=0}^{\infty} |a_n|^2 + |b_n|^2
\]

From Equation 1.2.3, it can be obtained that the magnitude of a certain harmonic on the DC side is related to \( D \) and \( m \) when the total duty cycle is determined. The power of a certain harmonic and \( D \) and \( m \) can be obtained through matlab. The relationship is as follows.
Figure 4. The relationship between a certain harmonic power and \(D_{on1}, m\).

It can be seen from the three-dimensional graph that the power of a certain harmonic will change with the change of \(D_{on1}\) and \(m\). Within the modulation range of \(D_{on1}\) and \(m\), that is, within the definition range, the harmonic amplitude will have a minimum value of the valley, so it can be seen that the amplitude of harmonics can be reduced by changing \(D_{on1}\) and \(m\). Through reasonable control and the values of \(D_{on1}\) and \(m\), a certain harmonic power of the input current on the DC grid side can be reduced, thereby reducing the electromagnetic interference of power electronic equipment to the DC grid.

4. Matlab simulation experiment
Matlab Simulink software is used to build the H-bridge DC converter circuit. The traditional pulse width signal and double pulse width signal are used to control the circuit. The circuit parameters are set to \(V_{in} = 100\text{V}; L = 0.001\text{H}, C = 0.00005\text{F}, R = 20\). The switching frequency is 10kHz and the average output voltage is 60V. The grid-side current was sampled with a sampling frequency of 100 kHz, and the power spectrum of the input measured current under the two modulation modes was analyzed by the welch method, as shown below:

Figure 5. Pulse width modulation.
It can be seen from the power spectrum that the peak value of the EMI on the grid side of the DC grid is concentrated at a multiple of the switching frequency. In order to reduce the power of the 6th harmonic, the method of 3.2 is used to determine the double pulse width control signal of $D_{on1}$ and $m$ that minimizes the amplitude of the 6th harmonic. It can be seen from the simulation results that the power of the 6th harmonic in dual pulse width modulation is 16.14dB lower than that of pulse width modulation, and at the same time, other harmonic powers can be controlled to remain unchanged. The simulation results show that the reduction effect of the double pulse width reaches 48dB even at the higher harmonics.

5. Conclusion
This paper proposes a dual pulse width harmonic suppression technique for H-bridge DC converter, analyzes the harmonic power spectrum of the DC-side current of the DC converter under dual-pulse-width modulation, and simulates it with matlab/Simulink software. By analyzing the simulated harmonic power spectrum, the correctness of the theoretical analysis is proved. Reasonable control and the values of $D_{on1}$ and $m$ can effectively reduce a certain harmonic power of the input grid side current. Provide a new idea for reducing the electromagnetic interference of power electronic devices without subjoining filters.

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