Modeling and Simulation of the Asymmetrical Half Bridge Converter

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Abstract. The Asymmetrical Half Bridge Converter (AHBC) realizes Zero-Voltage Switching (ZVS) of the switches by using its parasitic components in the circuit. The AHBC can get good input and output performances without much change in the whole circuit or large increase in the costs. In the paper, the average circuit model of the power stage and the small signal model of control circuit for AHBC are established by means of state-space-averaging method, the dynamic characteristics and stability are analyzed, and the compensator is designed. Finally, the stability and dynamic performance of the converter are verified by MATLAB simulation.

1. Introduction
In recent years, with the development and application of soft-switching technology, many high-efficiency circuit topologies have been proposed, among which Asymmetrical Half Bridge Converter (AHBC) is the typical Zero-Voltage Switching (ZVS) DC/DC converter that is suitable for medium and low power. The circuit adopts the complementary PWM control method of fixed dead zone to realize the ZVS of the switches through the leakage inductance of transformer and parasitic capacitance resonance of the switch tube, so as to achieving the purpose of lifting efficiency and reducing consumption [1]. It is very necessary to establish the mathematical model of the circuit in order to accurately predict the dynamic characteristics and stability of AHBC, thus effectively designing the control circuit. Based on the state-space-averaging method, the power circuit and control circuit of the converter are modeled, the transfer function of the circuit is obtained, and the compensation circuit is designed. The stability and dynamic characteristics of the converter are verified by software simulation.

2. The Modeling of Main Circuit

2.1. Asymmetric Half Bridge Topology
Figure 1 is the Asymmetrical Half Bridge Topology, and the duty ratios of the complementary conducting states of the two switches are d and 1-d respectively. Before modeling the circuit, we have the following hypotheses: 1) All the switch devices are ideal switches; 2) The switching frequency is much higher than the corner frequency of the Low Pass Filter (LPF); 3) The switching frequency is far higher than the disturbance signal frequency of the dynamic process; 4) The disturbance signal is smaller than the steady component.
2.2. State-space-averaging Model

Generally speaking, the modeling method of DC/DC converter often adopts the state-space-averaging method. This method starts from the state space equation of the converter at different stages, and after averaging, small signal disturbance as well as the processing of linearization, the stationary and dynamic small signal mathematical models of the converter are obtained, and then the whole circuit model is obtained. AHBC can be divided into 8 states in a switching cycle. Due to the space limitation, references [2] can be referred to model the equation of state at different stages of the circuit. Finally, the averaging model of the circuit is obtained as follows:

\[
K \frac{dX}{dt} = AX + BU, \quad y = CX + EU
\]  

Among it:

\[X^T = [v_1, v_2, v_3, v_4, i_p, i_m, i_t],\]

\[U^T = [v_{in}, 0, 0, 0, 0, 0, 0],\]

\[y = [i_s, v_n],\]

\[C = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix},\]

\[E = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},\]

\[K = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & -1/R_L & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & -n_d + (1-d)n_2 & -1 & 0 & 0 & 0 \end{bmatrix},\]

\[A = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},\]

\[B = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ d & 0 & 0 & 0 & 0 & 0 & 0 \\ n_d & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}.\]
If we make \( \frac{dX}{dt} = 0 \), then the DC model can be obtained:

\[
\begin{bmatrix}
V_m \\
V_1 \\
V_2 \\
V_3 \\
V_4 \\
I_p \\
I_m \\
I_{cp}
\end{bmatrix} =
\begin{bmatrix}
1-D & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1-2D & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -D & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & D & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & a & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & b & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & c & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix}
V_m \\
V_1 \\
V_2 \\
V_3 \\
V_4 \\
I_p \\
I_m \\
I_{cp}
\end{bmatrix}
\]

(2)

Among it: \( a = D(1-D)(n_1 + n_2) \), \( c = \frac{n_1(1-D)+n_1D}{R_c} \), \( b = \frac{D(1-D)(n_1 + n_2)}{R_c} \).

2.3. Small Signal Model [3]

Disturb the above equation of state, because \( C_{S1}, C_{S2} \) is very small, the \( \frac{dv}{dt} \) can be omitted. Since the disturbance of the current on the magnetizing inductance is relatively small, it can be omitted, finally we can obtain:

\[
v_3 = V_3 + \hat{v}_3, \quad V_3 >> \hat{v}_3, \quad v_4 = V_4 + \hat{v}_4, \quad V_4 >> \hat{v}_4(v_4 = v_2), \quad i_p = I_p + \hat{i}_p, \quad I_p >> \hat{i}_p
\]

(3)

\[
v_m = V_m + \hat{v}_m, \quad V_m >> \hat{v}_m, \quad d = D + \hat{d}, \quad i_L = I_L + \hat{i}_L, \quad I_L >> \hat{i}_L
\]

(4)

Plug the above expressions (3) and (4) into equation of state (1) and (2) and linearize them, and then convert them to the small signal model in the complex frequency domain. Finally, the input and output transfer function can be obtained as follows:

\[
G_{vi}(s) = \frac{\hat{v}_m}{v_m} = \frac{D(1-D)(n_1 + n_2)}{s^2L_fC_f + sL_f + 1}
\]

(5)

The transfer function of control and output:

\[
G_{vd}(s) = \frac{\hat{v}_m}{d} = \frac{(n_1 + n_2)V_m}{s^2L_fC_f + sL_f + 1}, \quad Z_{mv}(s) = R_c / sL_f // R_L \quad Z_{mv}(s) = \frac{1}{R_c} / \frac{1}{sL_f} = \frac{sL_f}{s^2L_fC_f + sL_f + 1}
\]

(6)

3. Modeling of Control Circuit

3.1. Modeling of Sampling Circuit

The sampling circuit obtains output of the main circuit \( v_o(s) \) through series resistance partial voltage, and the sampling output voltage \( v_f(s) \) serves as the input signal of the error amplifier. The transfer function of sampling circuit:
\[ H(s) = \frac{\hat{v}_f(s)}{\hat{v}_e(s)} \] (7)

### 3.2. Modeling of Pulse Width Modulator (PWM)

The PWM is actually a voltage comparator, as shown in figure 2. The amplitude of sawtooth wave is \( V_m \), the period is \( T_t \), and \( v_k \) is the output signal of error amplifier and compensation network. Compared with sawtooth wave, it outputs a pulse with duty ratio \( d \), which controls the two main switching tubes of the converter. The transfer function of PWM is:

\[ F_m(s) = \frac{1}{V_m} \] (8)

![Figure 2. PWM framework.](image)

### 3.3. Modeling of Error Amplifier and Compensation Network

The error amplifier and compensation network play an important role in the performance of the whole converter, and the selection of its parameters will affect the stability and dynamic characteristics of the whole converter. The compensation network is shown in figure 3.

![Figure 3. Figure 3 PID network.](image)

The transfer function can be deduced from the figure:

\[ G_c(s) = \frac{\hat{v}_k(s)}{\hat{v}_f(s)} = 0 = \frac{(1 + R_Cs)(1 + R_{C2}s)}{R_Cs(1 + R_Cs)} \] (9)

### 4. Modeling of Converter

According to the relationship between power circuit and control circuit, the voltage loop diagram of the whole converter can be obtained, as shown in figure 4. According to the voltage loop diagram of the converter, the open-loop transfer function can be obtained:

\[ T(s) = G_c(s)H(s)F_m(s)G_{cd}(s) \] (10)

Without compensation, \( G_c(s) = 1 \). The transfer function of the converter is:
The transfer function of the converter after adopting the compensator is:

\[ T(s) = \frac{(n_1 + n_2)V_m}{s^2 L_f C_f + s \frac{L_f}{R_e} + 1} H(s) \]

\[ \times (1 + R_C s) (1 + R_L C_f s) \times \frac{H(s)}{R_C s L_f + 1} \times \frac{(n_1 + n_2)V_m}{s^2 L_f C_f + s \frac{L_f}{R_e} + 1} \]  \( \text{(12)} \)

Figure 4. Voltage loop diagram of converter.

5. The simulation research

In order to study the stability and dynamic performance of Asymmetrical Half Bridge Circuit, MATLAB and PSPICE softwares are used to simulate it. Main parameters in the experiment: Vin =400V, V_o =30V, f_s =100kHz, L_f =0.117mH, C_f =150uF, n_1 = n_2 = 0.1875, R_L = 10Ω. When the converter is not compensated, its transfer function is:

\[ T(s) = \frac{5}{17.55 \times 10^{-3} s^2 + 11.7 \times 10^{-6} s + 1} \]

Figure 5 (a) shows the bode diagram of the converter without compensator and the crossing frequency of the converter \( f_c = 2.94kHz \), Phase Angle Margin \( \gamma = 3^\circ \). Figure 5 shows that the Phase Angle Margin of the converter is very small at this time, and the converter has poor stability. The PID compensator is designed, and the transfer function is:

\[ G_c(s) = \frac{3.53 \times 10^{-9} s^3 + 67.08 \times 10^{-6} s + 0.12}{42.14 \times 10^{-12} s^3 + 9.8 \times 10^{-6} s} \]

Figure 5(b) shows the baud diagram of the compensator. Figure 5(c) shows the baud diagram of the compensated converter, where the traversal frequency of the converter is \( f_c = 15.9kHz \), Phase Angle Margin \( \gamma = 56^\circ \).

The closed loop simulation of the converter is carried out using PSPICE software. The output voltage waveform of the converter is shown in Figure 8. After compensation, the converter achieves better stability and dynamic performance.
Figure 5. Bode diagram.
6. Conclusion
AHBC is a good choice for medium and low power high-frequency power supply because of its good soft-switching function. The main circuit model of the converter is analyzed and established, and the key parameters should be selected reasonably in the selection of compensation loop. Finally, the circuit is simulated by MATLAB to verify the stability and dynamic performance of the whole converter.

References
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