A new method to suppress the DC power supply voltage ripple

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Abstract. With the development of power electronics technology, how to improve the output quality of DC power supply has become an important subject of recent scholars' research. This paper put forward a new PWM control mode, the DC power supply output ripple is effectively suppressed. The theoretical basis is given by the principle analysis. Finally, the accuracy of the theoretical analysis is verified by simulation.

Introduction

With the development of power electronics technology, how to improve the output quality of DC power supply has become an important subject of recent scholars' research. DC power output ripple is too large mainly have the following effects: the capacitor load caused by resonance and harmonic current amplification, resulting in the capacitor due to overload or over-voltage damage; so that some electrical equipment, especially precision instruments and equipment work is not normal, or even damage; resulting in energy measurement and other detection instrument error.

Taking the Buck circuit as the research object, this paper presents a new type of PWM control mode, which can effectively suppress the output voltage ripple of the DC power supply.

Principle of double pulse width modulation

For the double pulse width modulation method in Figure 1, the first pulse conduction time is t_a , the second pulse conduction time is t_b , the two pulse interval is t_c , and t_a , t_b and t_c meet the following relations.

$$\begin{cases} t_a = D_{on1} \times T_s \\ t_c = D_{on2} \times T_s \\ D_{on} = D_{on1} + D_{on2} \\ t_b = D_{int} \times T_s < (1 - D_{on}) T_s \end{cases} \quad (1)$$

In the formula (1), D_{on1} is the duty ratio of the first pulse, D_{on2} is the duty ratio of second pulses, and the ratio of D_{int1} to the interval of two pulses is proportional to the period of control signal. Here we define 2 functions $H(n, D)$ and $G(n, D)$ as follows:

$$H(n, D) = \frac{D_{on2}}{D_{on1}} \quad (2)$$

$$G(n, D) = \frac{D_{int1}}{D_{on1}} \quad (3)$$

The $H(n, D)$ for switching period second pulses of the first pulse and the proportion coefficient ratio, $G(n, D)$ for two pulse interval time and the first pulse duration ratio coefficient; according to formula (1), type (2) and type (3) we can conclude that D_{on1} , D_{on2} , D_{int1} for mathematical expressions:

$$\begin{cases} D_{on1} = \frac{D_{on}}{1 + H(n, D)} \\ D_{on2} = \frac{H(n, D) \times D_{on}}{1 + H(n, D)} \\ D_{int1} = \frac{D_{on} \times G(n, D)}{1 + H(n, D)} \end{cases} \quad (4)$$

Fig.1 Single pulse modulation

Principle analysis of output voltage ripple

In order to further study the double pulse width modulation mode, taking Buck circuit as an example, the output current and voltage ripple and output current harmonics of Buck circuit under single pulse width and double pulse width modulation are analyzed and compared. Figure 2 is the schematic diagram of the Buck circuit.

Fig.2 Single pulse modulation

I_o is the output current size, the T_s is the switch period, and the D_{on} is the duty cycle of the switch period. The expression of the ripple of the output current in the period is:

$$\Delta I_{L-single} = \frac{V_s D_{on} (1 - D_{on})}{L f_s} \quad (5)$$

In the form of the switch, the frequency of the switch cycle. The fluctuation of the output voltage in the switch period is as follows:

$$\Delta V_{o-single} = \frac{\Delta Q}{C} \quad (6)$$

For the charge amount of the capacitor in the cycle, C is the capacitance of capacitance. We can calculate the charge of the capacitor in the switch period.

$$\Delta Q = \frac{1}{2} \frac{\Delta I_{L-single}}{2} \frac{T_s}{2} \quad (7)$$

To bring (7) into (6), we can get:

$$\Delta V_o = \frac{\Delta I_{L-single} T_s}{8C} \quad (8)$$

(5), (8) are the expression of the output current and voltage ripple of single pulse width modulation.

There are 4 operating states in a dual pulse width modulation circuit. Figure 3 is the working

waveforms of the circuit in the double pulse width modulation mode. In the picture, t_a is the first time of pulse opening, t_b is two pulse time interval, t_c is second pulse opening time, t_d is the time interval between second pulses and the next pulse.

Fig.3 Working principle diagram of double pulse modulation mode

$$D_{on1} + D_{on2} = D_{on} \quad (9)$$

The relationship between the interval of the pulse and the ratio of the period is as follows:

$$D_{int1} + D_{int2} = D_{off} = 1 - D_{on} \quad (10)$$

In the figure has the type: $t_d = D_{int2} \times T_s$;

$$\Delta I_{L-dual} = \begin{cases} \frac{V_s - V_o}{L} t_a; (D_{off} D_{on1} > D_{on} D_{int1} \&\& D_{off} D_{on2} > D_{on} D_{int2}) \\ \frac{V_o}{L} t_b; (D_{off} D_{on1} > D_{on} D_{int2} \&\& D_{off} D_{on2} < D_{on} D_{int2}) \\ \frac{V_s - V_o}{L} t_c; (D_{off} D_{on1} < D_{on} D_{int2} \&\& D_{off} D_{on2} < D_{on} D_{int2}) \\ \frac{V_s - V_o}{L} t_a - \frac{V_o}{L} t_b + \frac{V_s - V_o}{L} t_c; (D_{off} D_{int1} < D_{on} D_{int2} \&\& D_{off} D_{on2} > D_{on} D_{int2}) \end{cases} \quad (11)$$

$$\text{Put the four type } D_{on1} = \frac{D_{on}}{1 + H(n, D)}, \quad D_{on2} = \frac{H(n, D) \times D_{on}}{1 + H(n, D)},$$

$$D_{int1} = \frac{D_{on} \times G(n, D)}{1 + H(n, D)} \quad D_{int2} = D_{off} - \frac{D_{on} \times G(n, D)}{1 + H(n, D)} \text{ into (11), then we can obtain:}$$

$$\Delta I_{L-dual} = \begin{cases} \frac{V_s - V_o}{L} t_a; (\frac{G(n, D)}{H(n, D)} D_{on} > D_{off} \&\& D_{off} < G(n, D) D_{on}) \\ \frac{V_o}{L} t_b; (\frac{G(n, D)}{H(n, D)} D_{on} > D_{off} > G(n, D) D_{on}) \\ \frac{V_s - V_o}{L} t_c; (D_{off} > \frac{G(n, D)}{H(n, D)} D_{on} \&\& D_{off} > G(n, D) D_{on}) \\ \frac{V_s - V_o}{L} t_a - \frac{V_o}{L} t_b + \frac{V_s - V_o}{L} t_c; (\frac{G(n, D)}{H(n, D)} D_{on} < D_{off} < G(n, D) D_{on}) \end{cases} \quad (12)$$

Formula (12) is the relation between output current ripple and function $H(n, D)$ and $G(n, D)$. From the formula, we can see that the output current ripple can be changed by changing function $H(n, D)$ and $G(n, D)$.

Put the four type $D_{on1} = \frac{D_{on}}{1+H(n, D)}$, $D_{on2} = \frac{H(n, D) \times D_{on}}{1+H(n, D)}$,

$D_{int1} = \frac{D_{on} \times G(n, D)}{1+H(n, D)}$, $D_{int2} = D_{off} - \frac{D_{on} \times G(n, D)}{1+H(n, D)}$ into (2), then we can obtain:

$$\Delta I_{L-single} = \frac{V_s D_{on} (1 - D_{on})}{L f_s} = \frac{V_s - V_o}{L} (t_a + t_c) = \frac{V_o}{L} (t_b + t_d) \quad (13)$$

The comparison between (12) and (13) shows that no matter the value of function $H(n, D)$ and $G(n, D)$, the output current ripple of double pulse width modulation circuit is less than that of monopulse modulation mode, namely, output current ripple.

Therefore, we can conclude that double pulse width modulation can effectively suppress the output current ripple of the circuit, and suppress the magnitude of the current ripple, which is determined by the value of function $H(n, D)$ and $G(n, D)$.

From figure3, we can see that when $i_{L-dual} > I_o$, i_C is positive, C charges, and output voltage v_{o-dual} rises; when $i_{L-dual} < I_o$, i_C is negative, C discharge and output voltage v_{o-dual} decrease, so the capacitor suppression is in cyclic charge and discharge state. If the filter capacitor C is large enough, the v_{o-dual} can be regarded as a constant DC voltage V_o . When the C is not very large, the v_{o-dual} has a certain pulse, and the waveform in the diagram shows that the charge charge of the capacitor C in a switch period is:

$$\Delta Q_{dual} = \Delta Q_1 + \Delta Q_2 \quad (14)$$

$$\Delta V_{o-dual} = \frac{\Delta Q_{dual}}{C} \quad (15)$$

The capacitance current and voltage in Figure 3 can be equivalent to the formula (8), as shown in Figure 4.

Fig.4 Equivalent diagram of capacitor voltage in double pulse modulation mode
By the equivalent of figure 4, we can come to the following:

$$\Delta Q_{dual} = \frac{1}{2} \frac{\Delta I_{L-dual}}{2} \frac{T_s}{2} \quad (16)$$

by comparing (7) and (16), can be obtained:

$$\Delta Q_{dual} < \Delta Q_{single} \quad (17)$$

Because of this, we can get the expression of the voltage ripple under the mode of single pulse width modulation and dual pulse width modulation.

$$\Delta V_{o-dual} < \Delta V_{o-single} \quad (18)$$

Combined mode (13) and (18) can be seen that the output current and voltage ripple of the circuit are significantly suppressed when the circuit works in a dual pulse width modulation mode.

Simulation Result

In order to verify the principle of the previous analysis, this paper uses MATLAB to use the dual pulse width modulation mode Buck circuit simulation analysis , the specific simulation results shown in Table 1.

Table1 Double pulse modulation mode current, voltage ripple

	Ripple1	Ripple 2	Ripple 3	Ripple 4	Single Pulse
Simulation Current Ripple(mA)	121	149	125	123	316
Simulation Voltage Ripple(mV)	143	173	156	152	497
Experiment Current Ripple(mA)	156	186	153	159	353
Experiment Voltage Ripple(mV)	185	251	182	181	522

Conclusion

In this paper , Buck circuit is used as a model to propose a dual pulse width modulation method which can suppress the output voltage ripple. The theoretical basis is given by the principle analysis. Finally, the accuracy of the theoretical analysis is verified by simulation.

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