Analysis of Discharge Spark Energy in Buck Converter of a Continuous Mode of Inductive Current

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Abstract: The basic idea of intrinsically safe circuit and the discharge spark in the Buck converter in the explosive atmospheres were introduced. The Buck converter is the main topological structure of the switch type of intrinsically safe circuit, which has two working modes: continuous inductive current (CCM — continuous conduction mode) and discrete inductance current (DCM — discontinuous conduction mode). The operating state of the continuous inductive current mode is analyzed in detail and the energy of discharge spark in various operating modes is discussed. The total energy will decrease with the increase of switch frequency, in a switching cycle; the discharge spark energy has a maximum and a minimum value. Therefore, the Buck converter has smaller discharge spark energy than the linear power circuit and the switch type of intrinsically safe circuit can enhance the output power and the conversion efficiency of the intrinsically safe power.
Key words: Buck converter; discharge spark; intrinsically safe
CLC number: TB42

1 Introduction

With the increase of coal mine exploitation and the improvement of automation management, more and more devices are used in coal mines for examination, warning, monitoring and controlling. Most of these devices work in explosive air, so the electricity supplied for them must be intrinsically safe. At present there are two kinds of intrinsically safe power supply used in the coal mines. The first is the linear intrinsically safe power supply whose conversion efficiency is quite low and the adaptability of alternating current net is not good. So it is a traditionally intrinsically safe power supply. The second is the intrinsically safe power supply of the switch type, which belongings to the new-style power supply with the characteristics of high conversion efficiency and good adaptability to alternating current. What is more the output power can be raised by optimum design.

The switch intrinsically safe power supply mainly includes an AC/DC converter and a DC/DC converter. In the intrinsically safe circuit, the power frequency transformer is used for cutting down the voltage, commutating current, and wave filtering to form the AC/DC circuit. While the DC/DC transforming circuit uses high-frequency switch and PWM modulation technique to realize the energy conversion. Buck and Boost circuits are the basal topological structure of DC/DC convertion circuit. This paper analyses the working order of the Buck convertion circuit and the energy of discharge spark in detail.

2 Principles of Safe Electric Circuit

The standard of intrinsically safe circuit is that neither electrical spark nor hot effect produced under the standard condition (including the normal working condition and the permissible fault condition) can ignite the explosive air[1]. The basic principle of the intrinsically safe circuit is that the energy and heat effect of discharge spark are reduced by limiting the electrical parameters of the electrical devices, making the electrical spark or hot effect produced under the normal working condition and permissible fault condition be not able to ignite the explosive air[2], so that, the intrinsically safe power supply need not any special explosion-resistant enclosure and is safe and reliable simple in structure, small in volume, light in weight, and easy in application and maintenance[3–4].

3 Buck Converter

3.1 Constitution of the circuit

The Buck transfer circuit is a kind of DC single transistor converter and is not isolated, whose output voltage is nearly equal to the input voltage or a little lower than it. It is composed of the switch tube Q, the

Received 06 May 2006; accepted 08 July 2006
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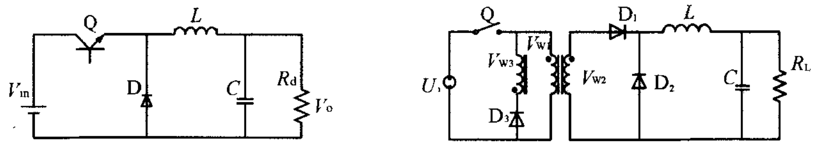
diode D, the output smoothing inductance L and the output smoothing capacitance C (the topological structure see Fig. 1a). By adding a high-frequency transformer, the Buck transfer circuit becomes an isolation forward converter (Fig. 1b). There are two modes: the Continuous Conduction Mode-CCM and Discontinuous Conduction Mode-DCM. The CCM mode is that the current which flows through the output smoothing inductance L is greater than zero. The DCM is that when the switch tube Q is switched the current which flows through the output smoothing inductance L is zero. These two working modes are not completely independent to each other because the electric parameter and load fluctuation enable the same circuit transform mutually between them, which means that there exists a critical continuous condition of the inductive current in CCM and DCM. At the right moment when the switch tube Q is switched off, the current which flows though smoothing inductance is just equal to zero[4–5].



(a) Topology of Buck converter (b) Isolation forward converter

Fig. 1 Buck transformation circuit

3.2 Types of discharge sparks

When the Buck transformation circuit works on the normal or failure condition, the possible types of discharge sparks are the spark discharge, the arc discharge, and the complex discharge of the former two. The spark discharge is produced by the discharge of a capacitor to disrupting the discharging gap, which is characterized by low electric voltage, big current discharge, and strong discharge energy. The high voltage arc strike disrupts the discharge gap to produce the arc discharge which can produce sustaining electric arc with a big current density. So the discharge energy is concentrated, resulting in a good ability to ignite surrounding explosive mixture. The compound discharge composed of capacity and inductance release greater energy than the single discharge does. According to theoretical analysis, the energy released by the compound discharge is equal to the summation of the instantly released energy by the power supply and the deposited energy by the inductance and the capacitor[6].

There exists a certain difference in energy value between the arc discharge and the compound discharge because of the mode of CCM (continuous) and the mode of DCM (discontinuous). This paper discusses the work process as well as analysis of energy in the Buck transfer circuit when the inductance current is continuous.

4 Working Process of the Buck Transfer Circuit

4.1 Working process

As shown in Fig. 1a, the working process of the Buck transfer circuit includes two stages.

In the [0, T_{on}], the switch tube Q is on; in the [T_{on}, T_s], the switch tube Q is off. The period of the switch is a $T_s=T_{on}+T_{off}$, the frequency of switch is $f=1/T_s$.

1) [0, T_{on}]

At $t=0$, the switch Q is on, the power supply voltage V_{in} is impressed on the diode D, the output smoothing inductance L, and the capacitance C. At the same time the diode D is switched off.

Because the voltage on the output smoothing capacitor equals to V_o, the voltage impressed on L is $V_{in}-V_o$. In this circuit there exists $V_{in} > V_o$ and the output smoothing current of inductance increases linearly. At $t=T_{on}$, the I_L reaches its maximum value I_{Lmax}.

2) [T_{on}, T_s]

At $t=T_{on}$, the switch Q is off, the inductive current I_L keeps flowing via the diode D. At this moment, the voltage impressed on the smoothing inductance L is $-V_o$, and the I_L decreases linearly.

At $t=T_s$, I_L reaches its minimum value I_{Lmin}. During the switch is on, the current via the Q is I_L. During the switch is off, the current via D is I_L[5–7].

4.2 Relationship of parameters

When the electric circuit works normally, from Fig. 2 we can see that the wave shape of the inductive current I_L and I_o is a triangular wave and varies between the I_{Lmin} and I_{Lmax} periodically. The I_o is the average output of current, whose minimum and maximum values are I_{Lmin} and I_{Lmax}. Now, let's discuss the following parameters:

Duty cycle $$D_y=\frac{V_o}{V_{in}} \quad (1)$$

Output current $$I_o=\frac{I_{Lmin}+I_{Lmax}}{2} \quad (2)$$

Current inductance

$$I_{Lmin}=I_o-\frac{1}{2}\Delta i_L(+)=\frac{V_o}{R_d}\left[1-\frac{R_d}{2L}(1-D_y)T_s\right] \quad (3)$$