Design of an Input-Series Flyback Power Supply for Ultra-Wide Input Voltage Range Applications

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Abstract. In view of the inconvenient power taking, bulky volume, poor anti-fluctuation capability, high cost and complicated control of ultra-wide input-voltage mine-used power supply, a low cost design scheme of ultra-wide input-voltage power supply based on input-series flyback is proposed. The switching power supply scheme adopts conventional MOSFET to realize the self-adaptability under ultra-wide input-voltage range. In this paper, the circuit structure and working principle of mine-used power supply and the design of multi-channel synchronous pulse drive circuit are introduced in detail, and the feasibility of the circuit design is verified by experimental prototype. The experimental results show that the power supply scheme is not only simple in circuit design and low in cost, but also has the advantages of strong input-voltage adaptability, high conversion efficiency, good voltage sharing effect and the like, which is suitable for mining electrical equipment with multiple input-voltage levels.

1. Introduction

Mine-used power supply plays a key role in the stability and safety of coal mine safety monitoring and gas drainage systems. Currently, the AC/DC conversion at the front end of the mine power supply generally adopts the conventional switching power supply or the combination of the tap change of the power frequency transformer and the conventional switching power supply [1-2]. However, there are many problems in coal mines, such as many voltage levels, large voltage difference between high and low input voltage levels, large fluctuation of input voltage, wide distribution of power supply locations and large volume of mine power supply, etc. The application of the above power supply will be very limited [3]. Since ultra-wide input-voltage switching power supply has the advantages of multi-input voltage level adaptation, high conversion efficiency and small volume, it will be the main implementation mode of AC/DC conversion for mining power supply. In the research of ultra-wide input-voltage switching power supply, the method of combining intelligent phase-shift voltage regulation technology with conventional switching power supply has the disadvantages of large volume, complex control, high cost, etc. [4]. The method implemented by two-stage topology DC conversion has complex circuit and relatively high cost [5]. The method implemented by three-level converter has complicated control logic [6]. Although the circuit is simple, the method realized by using single-switch flyback and two-switch flyback of SiC MOSFET is relatively high due to the high withstand voltage under high voltage and high current under low voltage of switch [7-8]. control of the implementation methods of ultra-wide input switching power supply studied in the above documents.
are relatively complex and relatively high in cost, it is not suitable for the application and promotion of medium and small power supply.

Flyback has the advantages of good isolation and low cost, and the combination of series switch can effectively reduce the voltage stress of single switch [9-10]. Hence, this paper will study the input-series flyback converter and verify the feasibility of the ultra-wide input-voltage power supply low-cost scheme in the application of mine power supply through a physical prototype.

2. Analysis of Main Circuit Structure and Working Principle
The input-series flyback converter is composed of a plurality of single-path converter connected in series, in order to simplify the analysis, the principle is introduced with the series number of 2 as an example. The main circuit structure is shown in Fig. 1. The input capacitor CD1, the inductor L1 and the switch S1 form the low-end converter circuit, the input capacitor CD2, the inductor L2 and the switch S2 form the high-end converter topology circuit, and the inductor L3, the diode D3 and the output capacitor CD3 form the output circuit. Since the input capacitor divides the input voltage equally, the voltage stress on the switch will be effectively divided equally. To keep the input parameters of the circuits of each converter consistent and simplify the output circuit, the number of turns of the input windings of each series converter circuit should be equally divided and the input and output windings share the transformer skeleton and magnetic core.

![Fig. 1 Circuit Structure of Series Flyback Converter](image)

Fig. 2 shows the current path during turn-on transition. When the switch is turn-on, the current in the input capacitor CD2 will flow to the inductor L2, and the current in the input capacitor CD1 will flow to the inductor L1, at which time the inductors L1 and L2 store energy. Since the same terminal of the output inductor L3 is opposite to the input inductor, the current of the load will be supplied by the capacitor CD3.
Fig. 2 Current Flow in Conduction Phase

For two inductors, the following typical relation can be obtained.

\[ i_{L1} = \frac{(V_1 \times D \times T)}{L} \quad (1) \]
\[ i_{L2} = \frac{(V_2 \times D \times T)}{L} \quad (2) \]

It can be seen from equations (1) and (2) that when the voltage values of \( V_1 \) and \( V_2 \) are equal, the current flowing into inductors L1 and L2 are the same.

When there is a deviation between the values of \( V_1 \) and \( V_2 \), it is assumed that the current flowing through inductor L2 will be greater than the current value in inductor L1 when \( V_2 \) is greater than \( V_1 \). According to Kirchhoff’s current law, part of the current flowing through inductor L2 will flow to input capacitor CD1 so as to reduce the deviation between input capacitors. After a certain cycle, the voltage values of input capacitors CD1 and CD2 will eventually divide the input voltage values equally. Hence, the input-series flyback converter can automatically realize the natural voltage equalization on the input side of the converter.

Fig. 3 shows the current path during turn-off transition. When the switch is turn-off, the input capacitors CD1 and CD2 are in a charged state. since the parameters of the capacitors CD1 and CD2 are consistent, the input voltage values will be evenly divided. The output inductor L3 will supply power to the load while charging the output capacitor CD3.

Fig. 3 Current Flow in Shutdown Phase
From the above analysis, it can be seen that the working principle and calculation method of input-series flyback converter are the same as that of single-switch flyback converter under the condition of ensuring the switch consistency. Assume \( n \) is the ratio of the primary and secondary windings, according to the volt-second balance principle of the transformer, the output voltage value of the power supply can be calculated according to equation (3).

\[
V_o = \frac{(V_{in} \cdot D)}{[n(1 - D)]}
\]  

(3)

3. Design of Synchronous Pulse Drive Circuit

To ensure the consistency of the multi-channel switch in the input-series flyback converter, this paper will control the multi-channel switch by controlling the charge of the input capacitance of the switch through coupling with the high precision capacitor. The specific circuit is shown in Fig. 4. The high-end and low-end driving circuits are composed of the same circuit. To simplify the analysis, this paper will only introduce the low-end driving circuit in detail. The low-side drive circuit mainly consists of pulse coupling capacitor \( C_3 \), turn-on diode \( D_5 \), damping resistor \( R_4 \), grid protection voltage regulator \( ZD_1 \), turn-off transistor \( Q_1 \), acceleration turn-off capacitor \( C_4 \), bias resistor \( R_3 \) and discharge diode \( D_4 \). Endpoints \( G_1 \) and \( S_1 \) in the low-side drive circuit correspond to the gate and source of the low-side switch, respectively.

![Synchronous Pulse Drive Circuit](image)

Fig. 4 Synchronous Pulse Drive Circuit

The working principle of the pulse drive circuit is as follows: when the drive pulse control signal changes from negative to positive. The input capacitor of the switch is charged through \( C_3 \) and \( D_5 \). When the \( V_{gs} \) of the switch reaches the opening threshold, the switch starts to turn-on, and then the charging voltage continues to rise until the switch is completely turn-on; When the driving pulse control signal is reversed from positive to negative, the charge in the coupling capacitor \( C_3 \) is discharged through the diode \( D_4 \), at the same time, the capacitor \( C_4 \) and the auxiliary accelerating triode \( Q_1 \) are turned on, and the input capacitor of the switch is rapidly discharged so as to quickly cut off the switch. The minimum capacitance of the coupling capacitance can be calculated from equation (4).

\[
\Delta Q = C \cdot \Delta U
\]  

(4)

4. Experimental results and analysis

Taking the mine power supply as an example, the three voltage levels \( AC127/380/660V \) commonly used in coal mines and considering the fluctuation margin of the input voltage, the input voltage range of the switching power supply is determined to be \( AC85–900V \), the output power of the power supply is determined to be 30W, and the output voltage is determined to be \( DC15V \). To verify the feasibility of the scheme, an experimental platform for flyback converter power supply with three-stage series
input is built. The platform consists of a filter rectifier unit and a three-input-series flyback DC converter power supply. The control chip in the main control circuit of the power supply adopts a peak current PWM controller NCP1253 which can reduce the frequency, and the switch adopts a conventional field effect transistor KPS11N65F.

The voltage waveform of the switch was tested under full load at AC85V and AC900V, and the test results are shown in Fig. 5.

![Voltage Waveform](image)

(a) Input Voltage at AC85V

(b) Input Voltage at AC900V

Fig. 5 Test Results of Switch Voltage Including Vos-s1-Vos-s3 when Po-30W

From the test waveform results, it can be seen that under the input voltages AC85V and AC900V, the synchronization of the three switch is good, and under the input voltage AC900V, the maximum voltage of the switch is only 512V, which is sufficient margin to the withstand voltage of 650V of the actual switch, and the difference between the maximum voltage of the three switch is small, which has a good voltage sharing effect.

The data in Table 1 are the general performance test results of the power supply.
Table 1. Test Results of General Performance

| Working voltage /VAC | Input power /W | Output voltage /VDC | Efficiency /% | Ripple /mV |
|----------------------|----------------|---------------------|---------------|------------|
| 85                   | 36.3           | 15.05               | 82.6          | 82         |
| 127                  | 35.8           | 15.04               | 83.8          | 76         |
| 220                  | 35.6           | 15.03               | 84.3          | 89         |
| 380                  | 35.4           | 15.05               | 84.7          | 102        |
| 660                  | 35.7           | 15.02               | 84.0          | 121        |
| 900                  | 35.9           | 15.04               | 83.5          | 132        |

From the results in Table 1, it can be seen that the maximum error of the output voltage of the power supply is only 0.3%, the maximum ripple value of the output voltage is 132 mV, which is lower than 250 mV required by the mining power supply, and the conversion efficiency of the switching power supply is as high as 84.7%.

5. Conclusion

In this paper, a low-cost design scheme of ultra-wide input-voltage range mine power supply based on input-series flyback conversion is proposed, which solves the high voltage stress of the power switch under high input-voltage through series switch combination mode, so that the wide input-voltage power supply can adopt the conventional MOSFET to realize self-adaptability under ultra-wide input-voltage through three-input-series combination mode. The experimental results show that the power supply based on input-series flyback conversion has the advantages of strong anti-fluctuation capability, good voltage sharing effect, stable output, high efficiency and the like, and is simple in circuit design and low in cost, and can be applied to small and medium power electrical equipment for mines with multiple input-voltage levels.

Profile of Author

LIN Yin (1978-), male, researcher, engaging in coal mine safety equipment research and development work in China Coal Technology Engineering Group Chongqing Research Institute, the main research direction for electrical explosion-proof technology, safety monitoring system, reliability design of electronic products and other related technologies.

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