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Design of Switching Power Supply for Intrinsically Safe Hydrogen Leakage Detection System

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Abstract

In the operation of large turbine generator sets, hydrogen is often used as a cooling medium to take away heat and maintain the normal operation of the set. However, hydrogen is easy to leak and not easy to be found, so it is necessary to measure the leaked hydrogen in real time. In order to ensure the explosion-proof performance and personal and property safety of hydrogen detection equipment, the design of an intrinsically safe switching power supply circuit for hydrogen leakage detection system to improve the explosion-proof performance of the equipment will be extremely important in both scientific research and commercial applications. Meaning. The author will explain the intrinsic safety technology background and development process, intrinsic explosion-proof technology and intrinsically safe power supply design.

Keywords

Hydrogen leakage, Intrinsic safety, Switching power supply, Explosion-proof technology.

1. The development process of intrinsic safety technology

The concept of intrinsic safety originated in the United Kingdom. It was proposed by Professor R.V. Wheeler in 1914 after conducting an in-depth analysis and research on the characteristics of electric spark ignition gas in the electric bell signal system. Based on this, British scholars drew up relevant regulations for intrinsic safety and designed the first spark experimental device. In the next few years, some equipment certified by the spark test device was widely used, and practice proved that these regulations are indeed safe. Since then, Intrinsic Safety (IS) technology has gradually been recognized by people and developed rapidly. By 1940, foreign researchers through continuous efforts have had a deeper level of research on the theory of intrinsic safety and applied it in practice. There have also been qualitative breakthroughs, and they have slowly begun to seek and formulate unified international standards. In 1970, the spark test device designed in Germany was adopted by various countries and became the IEC standard spark test device.

In the early 1950s, my country only began to conduct research on intrinsic safety theory, which was relatively late compared to some foreign countries. However, with the joint efforts of domestic experts, research in this area has a tendency to come from behind. In the early 1960s, my country produced relatively mature intrinsically safe explosion-proof electrical appliances for coal mines and put them into use. In the 1970s, industrial environments such as petrochemicals began to use self-made intrinsically safe products. In 1977, my country officially promulgated the standard of intrinsically safe explosion-proof technology. Intrinsic safety technology gradually attracted the attention of more domestic scientific researchers. The equipment for intrinsically safe explosion-proof electrical equipment has gradually increased. The research direction mainly focuses on intrinsically safe circuit systems and intrinsic safety. Research on circuit discharge theory and non-

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explosive evaluation method. In recent years, research on intrinsic safety technology has mainly focused on intrinsically safe circuit characteristics, power switch circuits, and intrinsically safe application design methods. In 2005, Liu Hui and others from Xi'an University of Science and Technology combined the design of intrinsically safe explosion-proof DC switching power supply to study the influence of output filter capacitor on the intrinsic safety performance of the power supply, and concluded that the energy released by capacitor short-circuit discharge is mainly concentrated in the initial stage of electrode closure. In 2008, Ma Steel of Dalian University of Technology designed an intrinsic safety system based on ZigBee for tracking and positioning of underground personnel, which improved the level of coal mine safety production monitoring and management. In 2010, my country officially promulgated the latest intrinsically safe explosion-proof standard GB3836.4—2010 "Explosive Environment Part 4: Intrinsic Safety Type "i"".

2. Classification of explosive hazardous substances and explosion-proof technology of intrinsically safe circuits

2.1 Classification of explosive hazardous substances

Explosive hazardous substances are gases, vapors, mists, dust and fibers that can mix with air to form explosive mixtures. my country divides explosive hazardous materials into three categories: Category I is mine methane; Category II is explosive gas mixture; Category III is explosive dust, fibers or fly floc.

Through the maximum test safety clearance (detonation transfer capacity) and the minimum ignition current ratio, the explosive substances of Class II can be further subdivided into IIA (propane), IIB (ethylene), IIC (hydrogen), and the degree of risk: IIA<IIB<IIC . The minimum ignition energy of different types of explosive substances is shown in Table 1.

Table 1: Minimum ignition energy of explosive substances

Category	Level	Ignite energy/mJ
I	-	0.28
II	A	0.20
II	B	0.06
II	C	0.019

Class II explosive equipment is divided into T1-T6 groups according to the ignition temperature.

Table 2: Maximum surface temperature

Temperature group number	Allowable surface temperature(℃)
T1	450
T2	300
T3	200
T4	135
T5	100
T6	80

2.2 Intrinsically safe circuit explosion-proof technology

According to the latest standard of GB3834.4-2010, intrinsically safe circuits are used to limit various electrical parameters or take protective measures so that any electric spark or any thermal effect generated by electrical equipment under normal conditions and prescribed fault conditions will not cause the prescribed explosive mixture to explode , So as to realize the explosion-proof performance of electrical equipment and avoid the occurrence of explosive accidents. According to the different

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degree of safety, intrinsically safe electrical equipment can be divided into two explosion-proof levels, ia and ib. For the ia level, when the circuit is in normal operation and one or two counting failures, it will not ignite the electrical equipment of the explosive mixture in the surrounding environment. It can be used in the 0 zone with greater danger; for the ib level, when the circuit is in During normal operation or a failure, electrical equipment with explosive mixtures in the surrounding environment will not be ignited, and it is generally only suitable for hazardous locations in Zone 1 and below. The safety level of Ia is higher than that of ib, and iaIIC level should be selected when designing in a hydrogen environment.

In a flammable and explosive environment, if the electric spark generated by electrical equipment reaches the critical value of explosive gas, the explosive material will ignite, leading to dangerous events. Among them, there are three basic forms of circuit discharge sparks, namely arc discharge, glow discharge, spark discharge and mixed discharge composed of three types of discharge. The arc discharge occurs when the switching device is switched under low current and low voltage, when the inductance is disconnected, and when the capacitor is discharged instantaneously. This phenomenon occurs, which is caused by the continuous conversion of some form of unstable discharge. Glow discharge generally occurs under high voltage and low current conditions, and it is almost hard to see in the intrinsically safe circuits studied, so it is not necessary to consider. For spark discharge, it generally occurs in the process of turning on and off a circuit with capacitance and inductance. The principle it produces is due to the breakdown of the discharge gap.

In summary, in the design of intrinsically safe switching power supply circuits, only two types of electric spark discharge need to be considered, namely spark discharge and arc discharge.

3. Intrinsically safe circuit design

In the design of intrinsically safe circuits, GB3834-2010 has clearly stipulated the allowable short-circuit voltage and current of the circuit and the corresponding capacitance, inductance and resistance values of the circuit according to the minimum ignition curve. The minimum ignition curve includes the minimum ignition current curve and the minimum ignition voltage curve. It is the critical parameter for igniting explosive gas mixtures determined by a large number of electric spark tests, and is an important basis for intrinsic safety design. At the same time, we must consider the corresponding safety factor when using the minimum ignition curve. The calculation formula is as follows:

$$U(I) = \frac{U_m(I_m)}{a}. \tag{1}$$

$\boldsymbol{U(I)}$ is the design maximum allowable voltage (current), $\boldsymbol{U_m(I_m)}$ is the minimum ignition voltage (current), and a is the safety factor. The value of the safety factor is shown in the table below.

Table 3: Safety factor value

Status	ia	ib
normal work	2.0	2.0
One faults	1.5	1.5
Two faults	1.0	-

The following figures are the minimum ignition curves of resistance, capacitance, and inductance in the circuit of explosive environment of class II.

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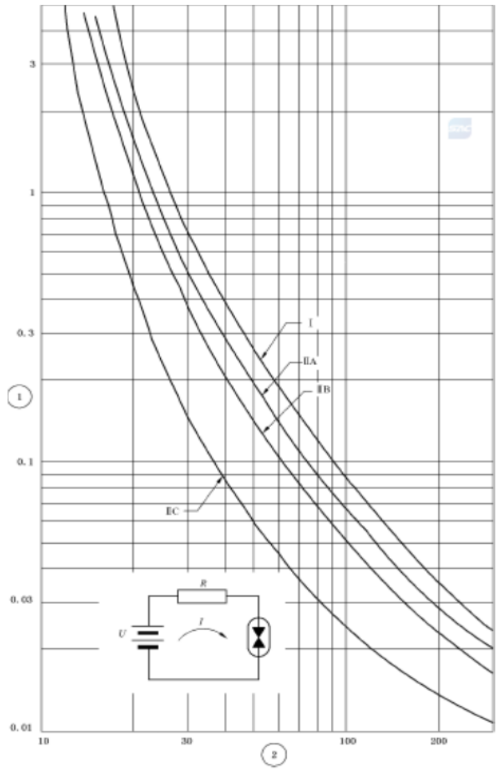

Figure 1: Type II resistance circuit

Among them, the ordinate is the minimum ignition current I (A); the abscissa is the power supply voltage U (V). It can be seen from Figure 1 that the safety level IIC>IIB>IIA, the greater the voltage, the smaller the corresponding current.

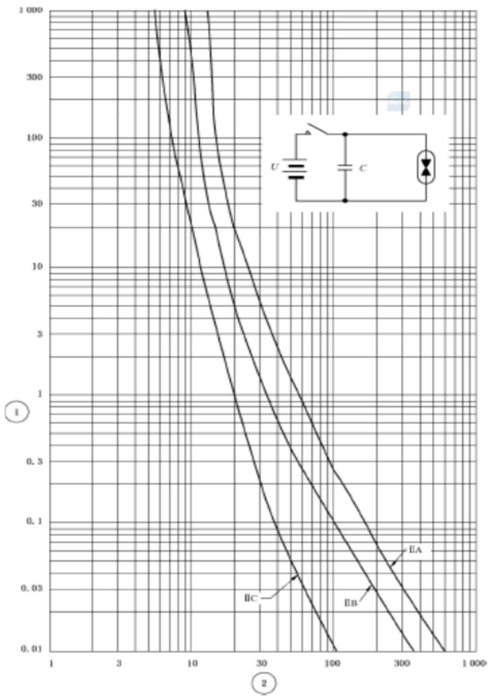

Figure 2: Class II capacitor circuit

Among them, the ordinate is the capacitance C (uF); the abscissa is the lowest ignition voltage U (V). Figure 2 shows that the larger the voltage, the smaller the allowable capacitance value.

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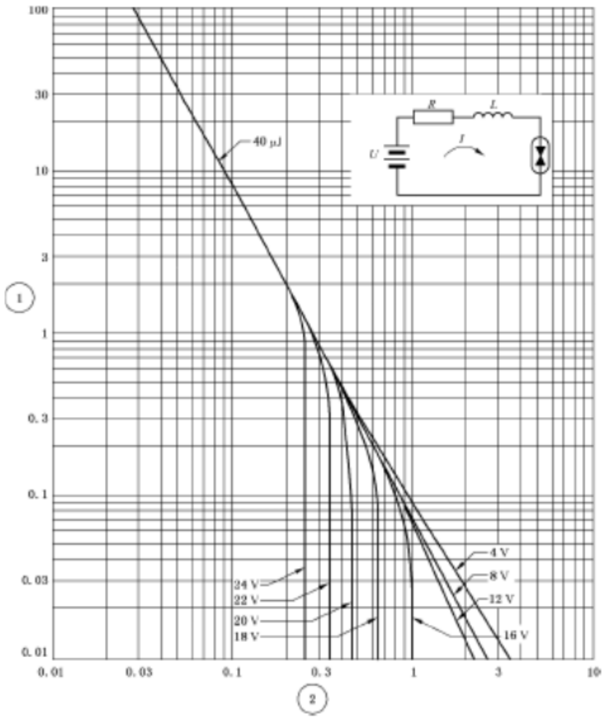

Figure 3: IIC inductance circuit

Figure 3 is the minimum ignition curve corresponding to different power supply voltages. Among them, the ordinate is the inductance L (H), the abscissa is the lowest ignition current I (A), and the energy level of the constant part of the curve is 40uJ. Therefore, by checking the minimum ignition curve, you can directly determine whether the resistance, capacitance, and inductance in the circuit meet the requirements of intrinsic safety.

3.1 Overall structure design

In order to improve the explosion-proof performance of the hydrogen leak detection system, an intrinsically safe power output is required. Its overall structure block diagram is shown in Fig. 1, mainly through anti-jamming circuit design, current-limiting circuit design, multi-level voltage conversion circuit design, and finally an intrinsically safe power output.

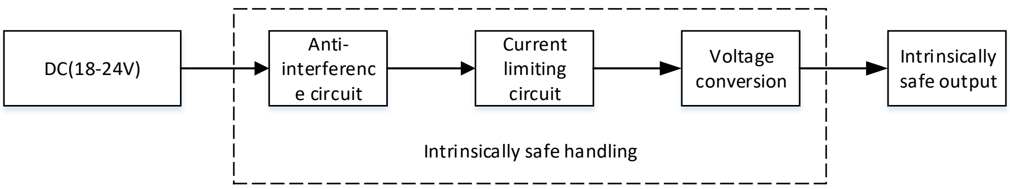

Figure 4: Intrinsically safe power supply structure diagram

3.2 Anti-interference circuit design

The anti-interference circuit of the system is composed of filter circuit and anti-surge circuit. The filter circuit is composed of capacitors and inductors. This circuit can filter out ripples and interference signals in the cable and improve the reliability of the DC power supply. However, capacitance and inductance are important factors that affect the intrinsic safety performance of the circuit, so their values in actual engineering applications meet the intrinsic safety requirements. The anti-surge circuit is to prevent overvoltage at the input terminal, which can effectively avoid damage

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to essential equipment components. It consists of fuse F1 and transient diode Z2. Transient diode is a high-efficiency protection device in the form of a diode, which has the characteristics of fast response, high transient power, low leakage current and small size. When the two poles of the TVS diode are impacted by reverse transient high-energy, it quickly changes the high impedance between the two poles into low impedance, absorbs up to kilowatts of surge power, and effectively protects the precision components in the electronic circuit from various surges Damage to the pulse. R7 is a current-limiting resistor. Metal film resistors or non-inductive wire-wound coating layer resistors should be used. Carbon film resistors should not be used, with an accuracy of not less than ±5%, to limit the discharge current and protect the power supply or capacitive circuit.

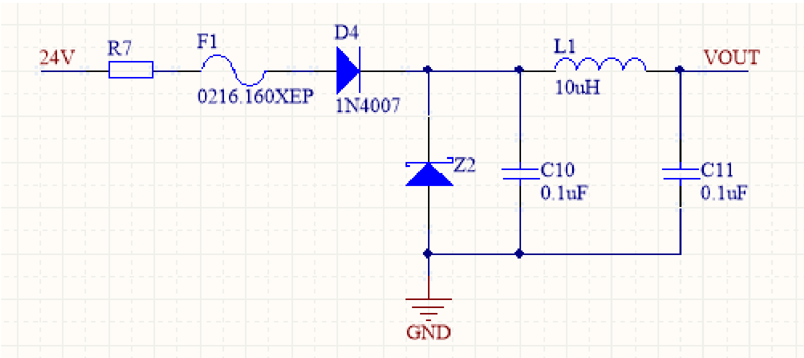

Figure 5: Anti-interference circuit

3.3 Current limiting circuit design

In order to prevent the switching power supply from being short-circuited or overcurrent at the moment of power-on, when the overcurrent protection value of the intrinsically safe power supply is exceeded, the intrinsically safe power supply may malfunction and the system cannot be used normally. The circuit design can limit the inrush current due to power-on within the specified range to ensure the normal operation of the system. The current-limiting circuit is shown in Figure 5. The resistance of the current-sense resistor R1 should be set according to the maximum current of the load. When the voltage drop of the resistor R1 exceeds the conduction voltage of the transistor Q1, at this time Q1 is in the on state and Q2 is in the off state , No current output; when the voltage of the resistor R1 drops below the turn-on voltage of the transistor Q1, at this time Q1 is in the off state, Q2 is in the on state, and the current passes normally. At the same time, in order to meet the intrinsic safety requirements, the circuit is designed for secondary protection to ensure that both the normal working state and the fault state can meet the intrinsic safety requirements.

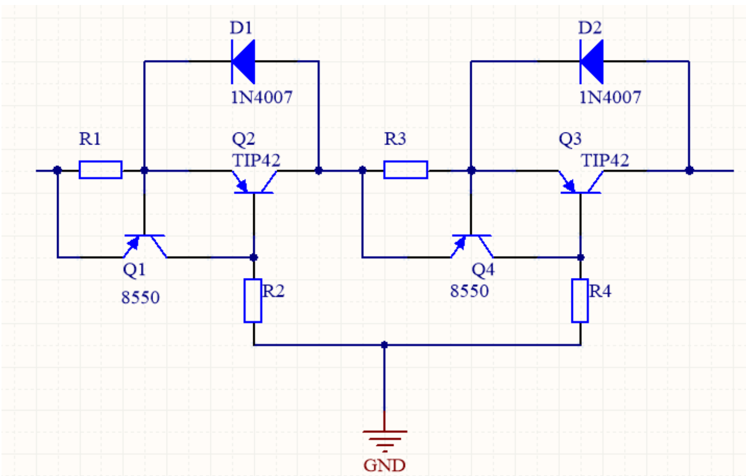

Figure 6: Current limiting circuit

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3.4 Multi-level DC-DC voltage conversion design

In order to meet the power supply requirements of the entire system, the intrinsically safe output DC voltage needs to be converted into multi-level DC voltage. For linear regulators, it has the characteristics of fast output voltage and low output noise, but its conversion efficiency is low, and large energy is generated when the current is too large. For general DC-DC converters, the quiescent current is small, but the switching noise is large. According to the characteristics of the two chips, a multi-level DC-DC voltage conversion design is designed to convert the essential DC output voltage into 5V, 3.3V, -3.3V. The specific circuit is shown in the figure below.

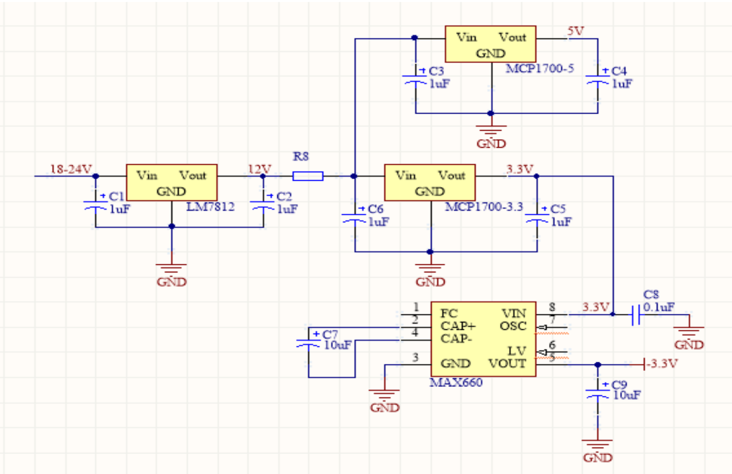

Figure 7: Multi-level DC-DC voltage conversion circuit

4. Conclusion

Aiming at the IIC environment with the highest explosive hazard, this article designs an anti-interference circuit, an overcurrent and overvoltage protection circuit, and a multi-level DC- The DC voltage conversion circuit design makes the switching power supply circuit reach the intrinsic safety standard, and improves the explosion-proof performance and reliability of the hydrogen leakage system.

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