Study on the application of multi-channel isolation power supply in non-equipotential circuits

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Abstract. In non-equipotential circuits, there is the problem that the switching tubes do not share a common ground. This paper therefore addresses this problem by designing a multi-channel isolation power supply (MCIPS). It mainly includes the square wave generation circuit, the high-frequency transformer and three-terminal stabilized circuit. This paper provides a detailed theoretical analysis of the design and principles of these three circuits. Using Multisim to model a MCIPS simulation circuit and derive the output waveforms of each circuit. The correctness of this solution was ultimately verified. The study of this power supply is of great importance for bridge circuits.

1. Introduction

With the development of power electronics technology, fully controlled switching devices, mainly MOSFETs and IGBTs, are widely used in power applications. To ensure the stability and reliability of each switching tube drive circuit, the power supply needs to be made into a multi-channel isolation. The isolated power supply ensures that each module is powered separately, preventing damaged modules from affecting the normal operation of other modules. As the drive signal corresponds to the gate and source of each switching tube, the different switching tubes cannot share a common ground with each other and the drive voltage between them floats to ground with the change of the source potential. The design of non-isotropic MCIPS is therefore of great importance.

There have been many studies on MCIPS. In the literature [1], an isolated drive power solution for driving IGBTs in inverter circuits is designed. This solution passes the DC current through the full-bridge inverter circuit and then outputs a high-frequency alternating square wave current. Finally, a current transformer to achieve magnetic isolation and multiple outputs. A drive power supply for IGBTs in three-phase inverters was designed in the literature [2-4]. The power supply uses a multi-winding transformer to achieve 4 mutually isolated outputs.

The paper is structured as follows. Section 2 details the design schematics for the MCIPS. Section 3 simulates each module by means of the power electronics simulation software Multisim and presents the simulation waveforms. Section 4 summarises the article.

2. Design of MCIPS

The performance specifications of the multiple isolated output switching power supply designed in this paper are as follows. Input voltage: 24VDC; output voltage: +15V/-9VDC; output current: 0.8A;
accuracy of output voltage: $\leq \pm 1\%$; voltage regulation: $\leq \pm 10\%$; load regulation: $\leq \pm 5\%$; output ripple coefficient: $\leq \pm 0.1\%$; operating ambient temperature: $-5^\circ C \sim 45^\circ C$.

The overall framework of the MCIPS is shown in Figure 1. After rectification and filtering, the industrial frequency power output is 24VDC. The 24V supply is fed into the square wave generation circuit and generates a 24V high frequency square wave. This square wave is fed to the primary end of the HF transformer. The other end of the primary side is connected in parallel with an isolation capacitor to filter out the DC and produce an alternating voltage of $\pm 12V$. Multiple winding outputs can be used on the secondary side of the transformer, thus enabling multiple isolated supplies. This paper uses 3 outputs. The output AC power is rectified by a full-bridge circuit and then connected to a three-terminal voltage regulator circuit. Outputs $+15V$, $-9V$ and GND per circuit. Finally, the switch is driven by a TPL250 optocoupler.

![Fig 1. MCIPS schematic diagram](image)

### 2.1. Square wave generation circuit

#### 2.1.1. Square wave generation circuit

The square wave generation circuit is shown in Figure 2. Where $V_1$ is a P-type MOSFET and $V_2$ is a 15V voltage regulator diode. The 24VDC power supply is connected to $V_2$ via resistor $R$ to ensure the proper conduction of the PMOS tube. The low voltage protection circuit in this circuit consists of a PMOS tube and a voltage regulator. When the circuit starts, the PMOS does not conduct. The post-stage circuit is powered down, thus protecting the post-stage equipment. The chip FDS8958A consists of two push-pull MOSFETs. The potential of pin 3 is 24 V and the potential of pin 1 is 0 V. Pin 4 and pin 2 are two square waves with dead zones generated by the gate drive circuit. When pin 4 is high, pin 2 is low and when pin 4 is low, pin 2 is high. Therefore, when the voltage at pin 4 is less than the voltage at pin 3, the PMOS tube turns on, the NMOS tube turns off. When the voltage on pin 2 is greater than the voltage on pin 1, the NMOS tube turns on and the output T2_1 outputs 0V.

![Fig 2. Square wave generates circuit](image)

#### 2.1.2. Gate drive circuit

The gate drive circuit of the FDS8958A chip is shown in Figure 3. LM555 timer connected as an oscillator circuit with 5V DC input and 5V high frequency square wave output. The frequency-halving circuit is mainly implemented by the chip 74HC74, which outputs two square waves with complementary levels. Dead-zone circuit consists of four NOR gates. Two of these are combined with a dichroic circuit to produce a square wave with a dead zone to drive the analogue switching circuit. This prevents the two waveforms from being switched on or off at the same time, causing a short circuit in the switching tube.
The various parts of the gate drive circuit are analyzed as follows:

(1) Timer circuits
The timer circuit is mainly composed of the LM555 chip. This article connects them into an oscillator circuit. 5V at the input can be obtained from a 24V supply via the 78L05 voltage regulator. As the period of the output rectangular wave is related to the charge and discharge time constant of capacitor C1 and the trigger voltage at TH and TR, the oscillation pulse frequency can be calculated using the three-element formula of the first-order RC circuit. From the three-element equation, charging and discharging time for oscillating circuits is:

\[ T = \tau \ln \frac{u_c(\infty) - u_c(0)}{u_c(\infty) - u_c(T)} \]

\[ T = R_1 C_1 \ln 2 \]

Then its oscillation frequency is:

\[ f = \frac{1000000}{2 R_1 C_1 \ln 2} \]

where \( \tau \) is the charge and discharge time constant of capacitor \( C_1 \), \( u_c(0) \), \( u_c(\infty) \), \( u_c(T) \) are the initial value of the voltage across capacitor \( C_1 \), the end value and the value at charge/discharge time \( T \) respectively.

(2) Frequency-halving circuit
In order to generate two complementary drive waveforms, the 5V high-frequency square wave output from the timer circuit is fed into the bifurcated circuit to generate two complementary waveforms with half of the original frequency. The frequency-halving circuit mainly uses the 74HC74 chip to implement the frequency division function. Set SD and RD inputs to high, 5V square wave input to CP pin of 74HC74 chip. If D is high when CP is on the rising edge, Q output is high. If D is low, then Q output is low.

(3) Dead-zone circuit
To prevent two switch tubes from conducting at the same time, the dead-zone circuit is designed in this paper. Dead time delay is mainly accomplished by chip 74H02. The chip consists of four NOR gates. The two NOR gates D2A and D2D and the R2C4 differential circuit act on the dead-zone circuit to complete the dead-zone circuit delay function. The inputs of the other two NOR gates D2B and D2C of the 74H02 chip are connected to the outputs of the frequency-halving circuit and the dead-zone circuit respectively. The output generates a square wave with dead zone to drive the analogue switch.

(4) Analog switching circuit
Analog switch circuit consists of MAX4622ESE chip. When the control input pin 15 is low and pin 10 is high, the switches corresponding to NC3 and NO2 are on. NMOS tube on and PMOS tube off for FDS8958A chip. When the control input pin 15 is high and pin 10 is low, the switches corresponding to NO1 and NC4 are on. PMOS tube on and NMOS tube off for FDS8958A chip. These complex drive circuits enable the push-pull control circuit of the two MOS tubes to obtain a...
reliable dead zone and good drive and switch-off effects. At the same time, switching losses and heat generation can be reduced, resulting in a high frequency square wave signal of 24 V at the output.

2.2. High frequency transformer circuits

Transformers are magnetic ring transformers. The magnetic ring transformer outputs the output AC voltage through a full-bridge rectifier circuit and then outputs the DC voltage. The magnetic toroidal transformer circuit is shown in Figure 4. 24 V square wave input at T2_1 on the original side, the other end is connected to a parallel capacitor to filter out the DC voltage, so that the input becomes ±12 V AC. The secondary side outputs ±24V AC. The output voltage of the toroidal transformer is then connected to the full bridge rectifier circuit. Full bridge rectifier circuit consists of two BAV99 chips with 34VDC output.

2.3. Three-terminal regulator circuits

Figure 5 shows the three-terminal regulator circuit with the LM7809 voltage regulator chip as the core.

The circuit input is connected by a rectifier circuit with positive and negative terminals of +24V and -9V respectively. Outputs +15V, -9V and GND via voltage regulator LM7809 and capacitors. Then connect to the TPL250 optocoupler. Figure 6 shows the circuit diagram of the TPL250 optocoupler driving the MOSFET. The trigger signals F1, F2, F3 and F4 of the TPL250 optocoupler are provided by the CPU. The output of the regulator circuit is connected to pins 8 and 5 of the optocoupler to supply power to the optocoupler. Since the upper two bridge arms of a bridge circuit have different source potentials, while the lower two bridge arms can share a common ground. The upper two bridge arms therefore need to be driven separately, while the lower two arms can share a common drive. In this paper, multi-channel isolation power supplies can be a good solution to the problem that the switching tubes do not share a common ground.
3. Simulation analysis of multi-channel isolation power supplies

Multisim is a software program dedicated to the design and simulation of electronic circuits. This paper uses Multisim software to build a MCIPS simulation circuit model. The simulated waveform of the gate drive circuit of the FDS8958A chip in the square wave generation circuit is shown in Figure 7.

![Fig7. Square wave circuit driven waveform](image)

Where (a) shows the timer circuit output waveform. After the 5V supply passes through the timer circuit, the output amplitude is 5V, the frequency is 30kHz and the duty cycle is 0.5. It determines the frequency of the entire drive power supply. From equation (2) above, after adjusting the values of resistor R1 and capacitor C1, the frequency of the power supply will be changed. The diagram (b) shows the Q and Q non-output waveforms of the frequency-halving circuit. It turns the 5V square wave output from the timer circuit into two complementary waveforms of the same amplitude and half the frequency to drive the analogue switches respectively. The graph (c) shows a comparison of the input and output waveforms of the dead-zone circuit. The timer circuit output square wave is buffered by D2D and D2A to produce a dead time delay. When the dead-zone circuit is input high, a low level is output after passing through D2D. At this point the 5V supply is charged to capacitor C4 via resistor R2 and D2A is input low and output high. After a certain time delay, the charging of capacitor C4 is completed, the input of D2A is high and the output is low. The diagram (d) shows a comparison of the waveforms at the output Q, D2A output and D2B output of the two-way circuit. The output waveform period at Q becomes twice as long as before. So when Q outputs 1 cycle, the dead-zone circuit outputs 2 cycles. Only when the dead-zone circuit and the dichroic circuit are both low, the drive waveform output is high. The output waveform therefore has a high duty cycle of 0.25. The diagram (e) shows a comparison of the waveforms at the output of the dichotomous circuit Q non, the output of D2A and the output of D2C. The results are similar to those in (d). The two outputs D2B and D2C are waveforms driven by the inputs of the analogue switching circuit. From the analysis of (d) and (e), it can be seen that the high levels in the two drive waveforms are located in the second half and the first half of the output waveform of the bifurcated circuit, thus producing a protective effect on the dead zone. The graph (f) shows the output waveform of the analogue switching circuit. Since the high level duty cycle in the input drive waveform is 0.25, the low level 9V duty cycle in the output 9V~24V square waveform is 0.25.

The analogue switching circuit outputs two square waves to drive the gate of the FDS8958A respectively. The square wave generation circuit then outputs a 24V square wave and connects to the primary side of the toroidal transformer T2-1. The other end of the transformer is connected to a shunt capacitor to filter out the DC so that the input becomes ±12V AC. The secondary output of the toroidal transformer is rectified by the rectifier circuit and outputs 34VDC. The simulation waveform is shown in Figure 8. Where (a) shows the 24V square wave output from the square wave generation circuit. Only when the input voltage of PIN1,3 of FDS8958A is 9V, the PMOS tube is on and the circuit outputs 24V. When the input voltage of PIN6,8 is 9V, the NMOS tube conducts and the circuit outputs 0V. The square wave generation circuit therefore has a duty cycle of 0.5. Where (b) shows the input AC waveform of a magnetic toroidal transformer. The 24V square wave is filtered by a shunt capacitor to remove the DC and then output ±12V AC as the AC input to the toroidal transformer. Where (c) shows the AC square wave output from the secondary side of the toroidal transformer. Where (d) shows the +15V and -9V waveforms at the output of the rectifier circuit after the three-terminal regulator circuit.
Three-terminal regulator circuit outputs +15V and -9V to independently supply the TPL250 optocoupler. Finally, the MOSFETs are driven by optocouplers to achieve reliable switch-off. Figure 9 shows the sine waveform of the output of a three-way isolated power supply acting on each MOSFET of the bridge circuit. Different waveforms can be output by adjusting the optocoupler trigger terminal.

4. Conclusion

This paper designs a MCIPS for non-equipotential circuits. The aim is to solve the problem that the switching tubes in this circuit do not share a common ground. The circuit proposed in this paper mainly consists of a square wave generation circuit and its internal gate drive circuit, a high frequency transformer circuit and a three terminal regulator circuit. The article begins with a theoretical analysis, followed by a simulation using Multisim software. Finally, the output waveforms of each circuit are analysed in detail to verify the correctness of this design scheme. This design solution is simple in structure, small in size, low in cost, and efficient in power supply.

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