Implementation of miniaturized power transmission system of ROV

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Abstract. As the basic guarantee for underwater operation of ROV, power transmission system provides energy security for ROV. Reasonable power transmission system design is an important guarantee for ROV comprehensive performance. This paper presents an ROV power transmission method based on matrix transformation. The method with the characteristics of low transmission loss and low transmission current which based on long-distance transmission of medium-voltage and power-frequency in the armored cable. By increasing the transmission frequency in the underwater end, it can reduce the volume of the underwater transformer which solves the conflict between the efficiency and the volume of underwater transformer. In this way, the space occupied by the transformer on the ROV can be reduced and the transmission efficiency can be ensured to meet the application requirements of the ROV with high power and efficient transmission.

Keywords: ROV, Power transmission, Matrix transformation, Implementation, System simulation.

1. Introduction

The first paragraph after a heading is not indented (Bodytext style). As the basis of ROV operation and control, the power transmission system is the power distribution and energy security center of ROV. and the basic guarantee for the motion, control and operation of the submersible. It mainly provides power and controls energy for ROV. At the same time, it is complete with the functions of electrical protection and state monitoring, etc., and the reasonable design of power transmission system is an important guarantee for the comprehensive performance of ROV [1]

When the ROV water surface unit transmits power to the submersible through the armored cable, in order to reduce the transmission current in the armored cable and reduce the size of the armored cable, the transmission form of medium voltage AC is most adopted, and the submersible provides power supply to power devices and control devices after transforming and rectification [2]. However, the disadvantage is that with the increase of the power of the submersible, the transformer volume will increase as well when enhancing the transformer capacity in the same situation, which can not efficiently use the limited space of the submersible, and even can not be achieved in the multiple conditions of constraints. If the surface unit adopts medium-voltage and medium frequency transmission mode, it can effectively reduce the volume of underwater transformer. But for large-depth ROV, due to the length of the armored cable, when conducting the long-distance transmission of medium-frequency AC, there will be a large loss in the armored cable, thereby resulting in reducing transmission efficiency [3]. In order to effectively solve the contradiction between the transmission efficiency and the transformer volume so as to meet the application requirements of small volume, high power and efficient transmission of the underwater transformer, this paper studies and designs the miniaturized power transmission system of the 6000 m deep sea electric ROV whose power demands and overall design requirements are considered comprehensively.

2. System composition

ROV is mainly composed of surface monitoring system, power transmission system, deployment system and submersible body. The composition of the ROV is shown in Figure 1.

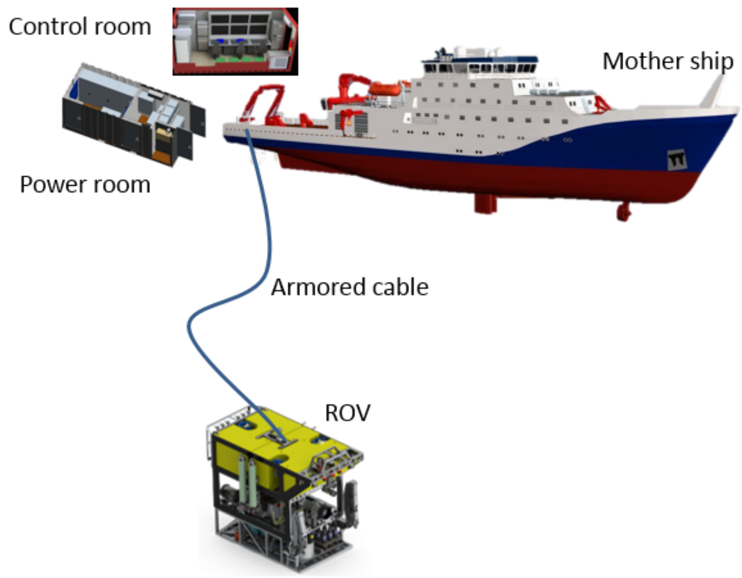

Figure 1. ROV composition diagram

Power transmission system is the power distribution and transmission center of ROV, and has the functions of electrical protection, condition monitoring, remote detection, logic control and more. It is mainly composed of water surface unit and underwater unit. The water surface unit is mainly composed of power distribution device, logic control device, signal acquisition device and transformer. The underwater unit is mainly composed of transformer, power distribution device, rectifier device and control device. The total input of the power transmission system is the marine AC power supply supporting the mother ship. According to the overall power distribution and control requirements of the ROV, the power transmission system will carry out safe and reasonable transformation, distribution, control, transmission and monitoring of the marine power supply.

The surface unit of the power transmission system is designed in such a way that power is transmitted to the underwater unit through the armored cable. In the design process, ROV power transmission with medium voltage transmission mode under the same power condition can reduce the transmission current in the armor cable, thereby reducing the size and weight of the armor cable, lowering the influence of the amored cable on the motion of the submersible, while facilitating the management of the amored cable.

When the medium voltage transmits, the surface unit will transmit marine power through the step-up transformer to the medium voltage transmission. Because the submersible body equipment and devices are usually low-voltage AC or DC power supply and control, after the medium voltage is transmitted the body, it needs to be stepped down in the body of the submersible and rectified for the use of the body equipment.

For the pressure-relief device of the submersible body, in the case of the same capacity and transformer ratio, the transformer volume decreases with the increase of the input frequency. As a result, the underwater transformer usually occupies a large space when the surface unit performs the power transmission to the submersible body by the medium-voltage and power-frequency method. If the medium-voltage and medium-frequency transmission mode can be adopted, the medium-voltage transmission method can not only reduce the transmission current in the armored cable, but also can reduce the transformer volume after the water surface unit steps up the marine electric pressure to medium-voltage, achieves up-sampling and transmission. However, there is a large power loss on the armored cable in the process of medium-frequency AC transmission. Because armored cable loss in the medium-voltage power frequency transmission is smaller, the underwater transformer is larger, the medium-voltage medium-frequency transmission underwater transformer is small, and the armored cable loss is large. In order to effectively solve the contradiction problem of the transmission frequency, the power loss on the cable and the larger volume of the underwater transformer, a miniaturized power transmission method based on matrix transformation is proposed in this paper.

The surface unit transmits power to the submersible body by the medium-voltage and power-frequency and the underwater unit undergoes power frequency increase and then undergoes voltage reduction and rectification treatment [4,5]. The schematic diagram of the power transmission system based on matrix transformation is shown in Figure 2.

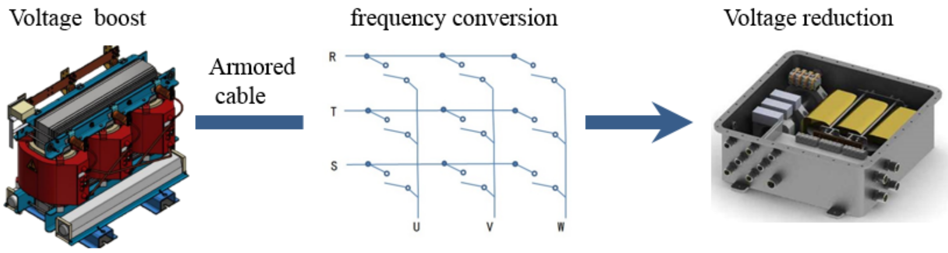

Figure 2. Schematic diagram of matrix transformation power transmission

3. Model establishment and simulation

3.1 Model establishment

The system model based on the matrix transformation is shown in Figure 3. The AC power of the mother ship is inputted by the power distribution unit and after being distributed by the power distribution unit, one way is converted to the water surface 220VAC control powe and the other way is outputted to the water surface transformer which is boosted to 3000VAC/50 Hz medium-voltage power AC and is transmitted to the matrix frequency converter unit of the underwater submersible. It is converted to 3000VAC/400 Hz medium-voltage and medium-frequency AC and sent to the medium-frequency converter unit which converts the medium-voltage and medium-frequency AC to multiple low-voltage and medium-frequency AC. The rectifier unit rectifies the multiple low-voltage and medium-frequency AC into the AC power supply inputs for ROV as well as the DC power supply inputs for the control system in accordance with the actual requirements of the load and the control system [6].

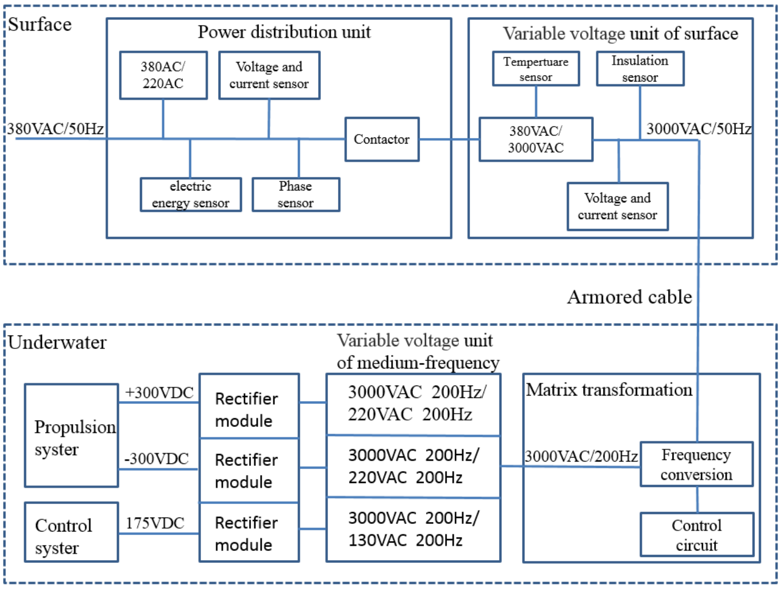

Figure 3. The model of matrix transformation power transmission

3.2 Simulation implementation of matrix converter

Matrix frequency conversion is the core part of the simulation model, which is mainly composed of switching matrix and modulation module. The modulation module is mainly divided into three parts, the virtual rectifier module, the virtual inverter module and the switch state composition module [7], as shown in Figure 4.

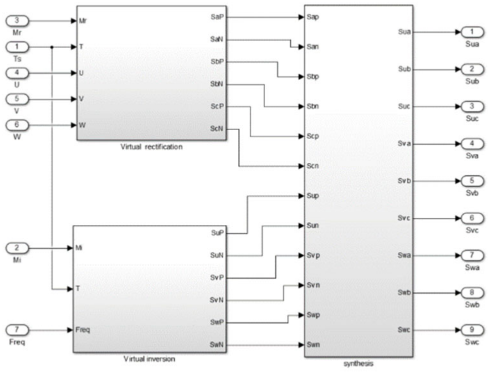

Figure 4. Schematic diagram of modulation module

3.3 Simulation conditions settings

In this paper, with reference to the engineering application of ROV, the power transmission system model is established based on the matrix frequency conversion structure. Matrix frequency converters require parameters such as modulation period, modulation ratio, output voltage frequency, etc. In this paper, the switching frequency of 5k, i.e., the sampling period TS = 0.2 ms, is adopted. Since it is not required to be stepped down by the matrix converter, the modulation ratio of the virtual rectifier side and the virtual inverter side is $M_r = M_i = 1$, in order to reduce the volume and weight of the subsequent step-down transformer. Considering practical engineering application requirements, the output voltage frequency is set to 400 Hz, and the other parameters are referred to the actual engineering project as shown in Table 1.

Table 1. Parameter table of medium frequency transformer unit

	Line voltage	Capacity	Connection Mode
Input winding	3000 VAC	36 KVA	Star
Output winding 1	220 VAC	12 KVA	Star
Output winding 2	220 VAC	24 KVA	Triangle

3.4 Simulation results

The virtual rectifier side and the virtual inverter side reference vector phase angle and sector judgment are shown in Figure 5 and Figure 6, respectively. The reference vector phase angle and the sector value on the virtual rectifier side and the virtual inverter side change periodically at frequencies of 50 Hz and 400 Hz, respectively.

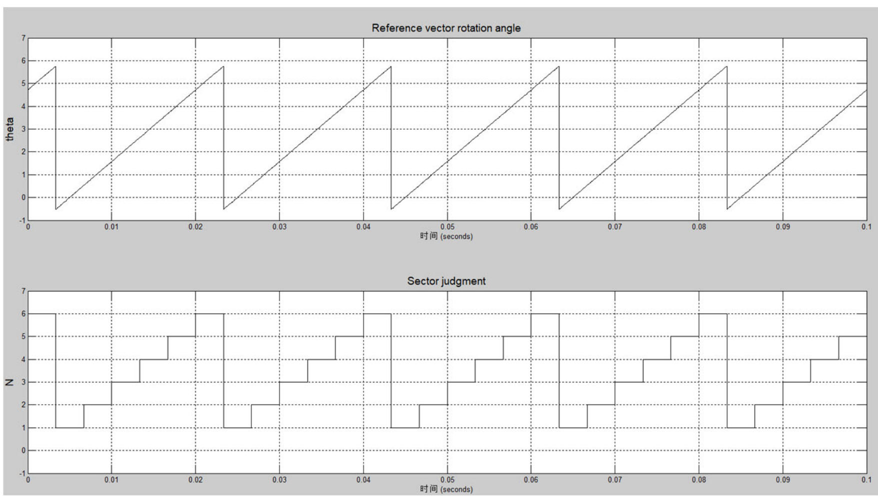

Figure 5. Reference vector phase angle and sector judgment of virtual rectification side

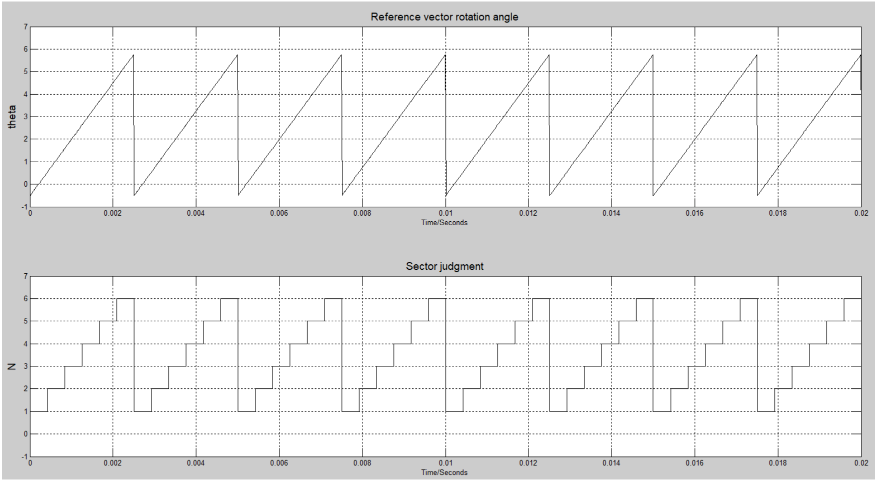

Figure 6. The phase angle of the reference vector and the sector judgment of the virtual inverter side

As shown in Figure 7, the input line voltage, the output line voltage and the secondary side line voltage waveform of the voltage conversion unit of the matrix converter can be seen that the input of the matrix converter is 3000 V/50 Hz AC, and it is converted to 400 Hz pulsating AC through the matrix converter, and then the step-down voltage is performed.

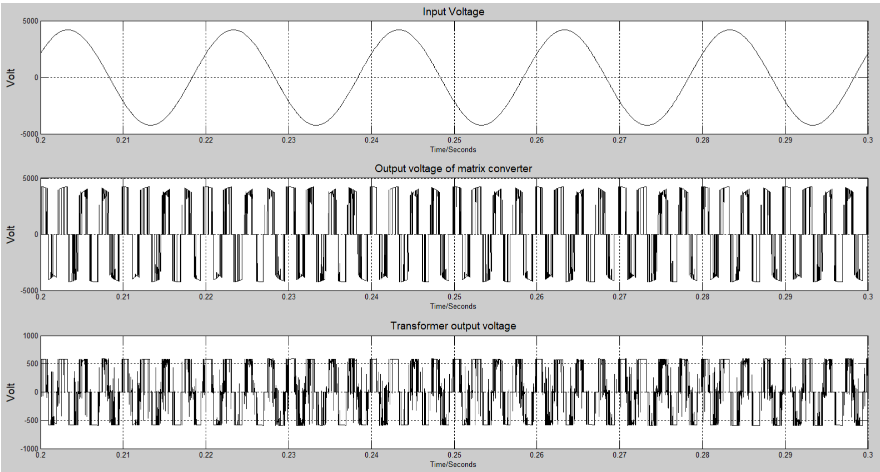

Figure 7. The process diagram of frequency conversion

4. Principle and composition of matrix frequency conversion unit

The matrix frequency conversion unit adopts the modular design, which is composed of a protection module, a filter, a main switch module, a control module, an interface module [8, 9]. Its schematic diagram is shown in Figure 8.

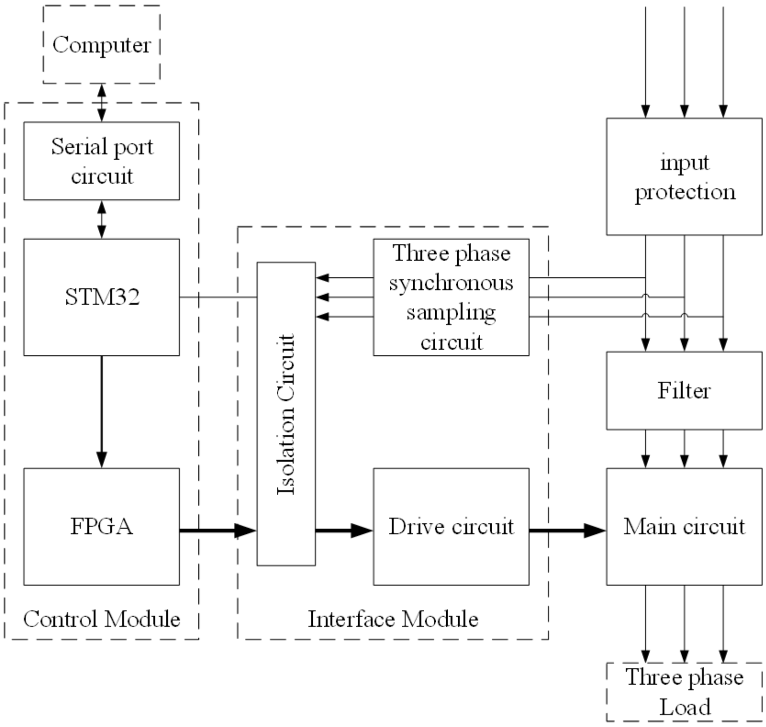

Figure 8. Schematic diagram of matrix converter

For 3000VAC, it is necessary to use the medium voltage circuit breaker as the over-current protection device of the circuit, which has a large volume and is an active device, so the protection module of the main circuit is set in the water surface power distribution unit. The main switch module, the control module, the filter and the interface module are located in the body of the submersible.

The main switch module is a 3 × 3 matrix frequency inverter switch matrix, consisting of 9 groups of inverted series IGBT switches, with a total of 18 switches tubes.

The control module is the control core of the matrix frequency conversion unit, which consists of STM32 circuit, FPGA circuit and serial port circuit. The serial port circuit is the interface between the upper computer and STM32.

The interface module consists of isolation circuit, drive circuit and three-phase synchronous sampling circuit.

4.1 Main switch circuit

For the matrix converter of 3000VAC, the control circuit and the main switch circuit require strict electrical isolation. Since each node of the common emitter type anti-serial structure matrix needs to set up a single isolated power supply, with a total of 9. The common electrode type anti-serial structure matrix, an input phase and an output phase are each connected to the three IGBT emitters, which can share the isolated power supply, and a total of 6 isolated power supplies are required. In order to simplify the main circuit structure and reduce the device volume, the main switch circuit is designed in the form of a common electrode type anti-series structure, and the main switch circuit topology is shown in the following figure [10].

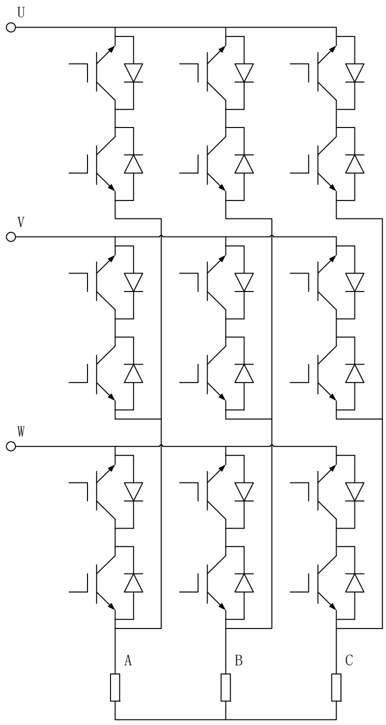

Figure 9. Main switch module topology

As the core device of the main switching circuit, in order to meet the requirements of 3000V voltage resistance, if IGBT adopts the switching tube in series, the peripheral circuit needs to be adapted to more passive components, and at the same time, subject to the limitations of 6000m of water depth, thus it needs to increase the volume and weight of the pressure-resistant structure. According to the requirement of engineering application, it is proposed to adopt FZ250R65KE3 IGBT, whose topological structure is a single IGBT plus anti-parallel diode. Its emitter electrode voltage is 6500 V, and the continuous DC electrode current is 250 A.

4.2 Control module

The control module is responsible for realizing the control strategy of matrix frequency conversion. This paper adopts the framework of STM32+FPGA, in which STM32 realizes the calculation of phase detection, sector judgment, vector action time calculation and switch time calculation, etc., and finally sends the switches timing of the virtual rectifier and the virtual inverter circuit to the FPGA through the parallel port. FPGA is responsible for PWM modulation, space vector composing, dead time setting and safe commutation strategy implementation.

STM32 uses 32-bit STM32F767 processor with integrated floating-point operation unit and main frequency up to 216 MHz, which can quickly complete the calculation of the control strategy. Because the dead time settings and the demands to implement a safe communication strategy will be very high on the controller's signal synchronization requirements, the ability to run concurrently with the FPGA can be achieved in 18-way PWM signal synchronous modulation, while ensuring that the timing output has a higher degree of stability, but the performance requirements of the FPGA is relatively low, so the EP4CGX15BF14C8 equipped with 14,400 logic units and 72 I/O of Alter a Cyclone IVGX series with the maximum operating frequency of 200 MHz is sufficient to meet the needs of the PWM generation.

4.3 Interface module

The interface module consists of isolation circuit, drive circuit and three-phase sampling circuit.

The isolation circuit is responsible for the electrical isolation of the control module and the main switch module. This paper adopts the isolation driving scheme of the active drive. The IGBT adopts the driving scheme of ±15 V driving voltage, R_{Gon} = 3 Ω, R_{Goff} = 20 Ω gate switch resistance.

In terms of isolation power supply, H2405S-2W (5 VDC) is used for power supply for digital isolator, and G2415S-2W (±15 V) is used for power supply of drive circuit. The isolation voltage of isolation power supply is 6000VDC, its peripheral circuit only needs one filter capacitor, and has self-recovery short-circuit protection function, which is suitable for the engineering application of this paper.

According to the practical engineering experience, the optocoupler usually does not have the ability to withstand the large depth of water pressure, so the isolation chip adopts the digital isolator IL715 giant magnetoresistance isolation chip, which has 110 Mbps bandwidth and 6000 VRMS isolation voltage level, meet in the engineering application requirements.

The voltage level and driving ability of the digital isolation chip usually cannot provide the demand of ±15 V voltage level and continuous high pulse current required by IGBT driving, and the later stage driving circuit is required to carry out voltage conversion and enhance over-current ability. In this paper, high-speed operational amplifier combined with FET transistor is used to realize the voltage level improvement and the conversion from monopolar to bipolar level, as well as the enhancement of driving ability. The operational amplifier is selected as THS4631 with a medium voltage slew rate of 1000 V/μ s and a maximum input voltage of 32 V (± 16). The selection of FET transistor needs to consider the parameters such as drain source voltage, continuous drain current and pulse drain current, with a view to match the voltage level, charge power and maximum charging current required by IGBT driving. The selection of FET transistor is SSM3J332R (P channel) and SSM3K335R (N channel) of Toshiba company.

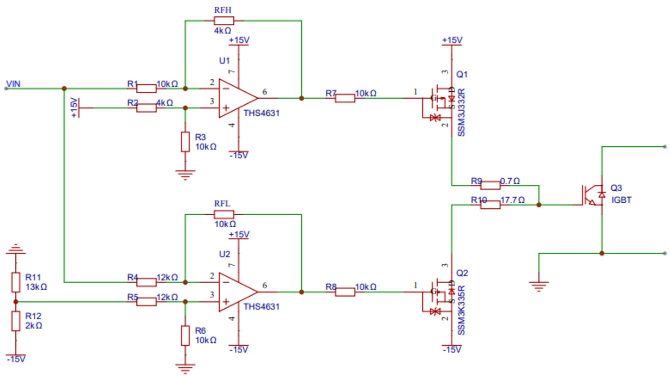

Figure 10. Design drawing of driving circuit

IGBT charge and discharge is using a completely independent loop. In order to ensure that the drive circuit two MOS transistors do not turn on at the same time, the peripherals circuit is built a substraction circuit, so that the two MOS transistors do not intersect.

The basic circuit topology of the subtractor is shown in the figure above, and the corresponding voltage transfer function is:

$$U_O = -\frac{R_f}{R_1}U_{i1} + (1+\frac{R_f}{R_1})\frac{R_3}{R_2+R_3}U_{i2} \tag{1}$$

In the actual circuit design, the output of the digital isolation chip is U_{i1}, 0-5 V level, and U_{i2} can be configured as any constant value in the range of ±15V by resistance dividing. The design of the upper bridge arm PMOS transistor Q_1 is [3 V, 5 V], and the lower bridge arm NMOS transistor Q_2 is [0 V, 2 V]. According to the gate threshold voltage of the FET transistor, the threshold voltage of the P transistor is -1.2 V, the threshold voltage of the N transistor is 2.5 V, and the output threshold voltages of the two operational amplifiers are 15-1.2 = 13.8 V, and -15+2.5 = -12.5 V, respectively.

According to the voltage transfer function, the feedback coefficient R_f/R_1 can be solved, and then the values of R_2, R_3 and U_{i2} can be reasonably allocated. The choice of charging resistance combines the parameters of IGBT internal gate resistance to achieve R_{Gon} = 3 Ω, R_{Goff} = 20 Ω.

5. Conclusion

In this paper, a miniaturized power transmission method based on matrix transformation is proposed. A model of matrix transformation power transmission system based on electric ROV is established and the simulation is carried out. According to the engineering application, the hardware construction and selection of matrix transformation unit have been carried out. The power transmission system proposed in this paper has the advantages of low transmission loss and the the volume of medium-frequency underwater transformer can be reduced 90% of the volume of power-frequency transformer. This provides favorable support and theoretical basis for the engineering application of high-power and miniaturized electric ROV.

Acknowledgments

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