Design of UPS System for a certain type of Ship-borne Radar’s Transmitter

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Abstract: The space experimentation missions are require high risk and high success rate. And the remote control command sent by TT&C equipment must be real-time and accurate. So the TT&C radar’s transmitter must be high reliable. As the characteristic of high Power requirement of ship-borne radar’s transmitter, the off-line UPS system is designed in this paper. It uses batteries that provide about seven hours of stable power supply, and the corresponding DC-AC inverter is selected and used. The design of this UPS system is reasonable, and the simulation of DC-AC inverter’s discharge based on Simulink reflects that this UPS system can meet the power demand of radar’s transmitter, so it’s practical and can be used widely.

1. Introduction
The ship-borne radar’s transmitter doesn’t have a UPS system, and the ship’s power supply is unstable and easy to break down. So there is need to design a UPS system for the transmitter. Then power supply can be monitored and transmitter can also be protected. Finally the reliability of the transmitter can be improved. According to experimental statistics, the power consumption is about 6000W in the process of the transmitter’s high-power use. During the space TT&C mission, the transmitter will output power about one hour, and it requires that the UPS system can provide more than one hour of power to the transmitter steadily. If the transmitter’s power supply is broken down during the mission, not only the mission will be failed but also a malfunction of the transmitter may be caused, and even bring immeasurable loss.

Combined with the actual situation of the transmitter and the working experience of post personnel and experts, this off-line UPS system is designed. At first, combined with the actual situation of transmitter, the overall plan of the UPS system is designed. Then aimed at the problem of high power consumption, high-power battery packs are used and the stable and safe charging scheme is designed. At the same time, the single-phase full-bridge inverter is applied in the discharge plan so that discharge loss can be reduced. For coordinating the charge and discharge circuit control, the overall architecture of full digital control with on-line monitoring function based on DSP is adopted, it generates PWM wave to control the IGBT switches, and PI-type controller is adopted to control the output voltage and current [1]. This UPS system is designed reasonably for the high-power transmitter, it’s reliable and can provide guarantee for reliable operation of the radar’s transmitter.

2. Overall scheme design of the UPS system
The UPS system takes DSP as the core control unit. It adopts PWM control technology, full bridge soft switching power conversion technology, boost DC-DC power conversion technology, etc. It’s a full digital control UPS system with flexible charge and discharge conversion which also have Real-time monitoring function of power supply. Its system block diagram [1,2,3] is shown in Fig. 1.
As shown in Fig. 1, the UPS system consists of charging circuit, discharge circuit and DSP control module. As this UPS is designed as the transmitter’s backup power, when the ship electricity is normal, static switch works in bypass mode, the transmitter’s power is supplied directly from the ship, at the same time DSP control the charging circuit to charge the battery pack until it is full. When the ship power is fault (no electricity, voltage is too high or too low), the static switch automatically switch to inverted state, the battery discharges, DSP control the inverter to work, then the power supply will be provided to the transmitter uninterruptedly.

The control unit uses DSP as the control core, which can generate the PWM wave, and it will drive the charging circuit through the optocoupler. At the same time, the IGBT switch of the inverter in the discharge circuit will be drove by SPWM wave in the same way. The closed-loop control is applied in the DSP’s control software through sampling circuit to obtain a stable discharge current and voltage. Charge and discharge protection circuit is applied in the system, once over-voltage, over-current and other faults occur, the UPS system will be shut down immediately, and the static switch will be switched to ship power. In addition, this system has good human-computer interaction function. Keyboard module is used to set charging and discharging strategy. LCD Module real-time displays charge and discharge voltage and current, charge and discharge mode, battery’s temperature, etc. Then the transmitter post personnel will know the current charge and discharge status in time.

3. Design of battery pack and charging scheme

The choice and design of battery pack determines the time it can power the load in case of the ship's power failure. In this UPS system, sealed maintenance-free lead-acid batteries are used. The backup time is designed to be 1 hour, the output rated power is 20KVA, the nominal output power factor is 0.8, the output efficiency of batteries is 0.9, and the critical discharge voltage of storage battery is about 10.2 V. From the above parameters, the maximum discharge current of the battery can be obtained as follows:

\[
I_{\text{max}} = \frac{P \cos \varphi}{\eta E_{\text{critical}}} = \frac{20000 \times 0.8}{0.9 \times 10.2 \times 20} = 87 A
\]

\[
C_{\text{battery}}(Ah) = \frac{I_{\text{max}}}{\text{Discharge rate}} = \frac{87}{1} = 87 Ah
\]

To summarize, the battery pack consists of 20 batteries with capacity of about 90 Ah, which is connected in series.

Before charging the battery pack, the initial state of the batteries shall be identified at first. Then, as the initial state in different stages, the corresponding charging control schemes are different. At first, when the batteries start charging, trickle charging is taken to make the battery pack reach the minimum threshold for fast charging, by the way, the battery pack can be maintained. In the stage of fast charging, the battery pack can be charged stably at constant current. At last, when the capacity of
the battery pack approaches the rated capacity, its acceptable charging current tends to zero. To avoid power loss and battery damage, the fast charging must be stopped. Then the battery pack will be charged to full in the charging stage of constant-voltage charging.

In the UPS system, diode full bridge rectifier is adopted, whose output is the input of battery pack’s charging circuit. The charging circuit is a passive clamped full-bridge ZVZCS PWM DC-DC converter, whose circuit structure is shown Fig.2. The converter uses phase shift control. IGBT Q1 and Q2 constitute the leading bridge arm, and IGBT Q1 and Q2 constitute the lagging bridge arm. The leading bridge arm’s zero voltage switch technology is realized by getting IGBT switch paralleled with the capacitor. The lagging bridge arm’s zero current switch technology is realized by outputting to the auxiliary passive clamping circuit which consists of coupled inductor Lf, maintenance capacitor Cb, diode Db and Dc. Tests show that charging circuit can satisfy the different stages of battery pack’s charging.

![Figure 2. Design of charging main circuit](image)

4. Design of discharge scheme

As the DC-AC inverter’s input voltage is 380~400V, the DC 240V of battery pack must be converted to 400V first. In this UPS system, the boost DC-DC circuit is adopted, whose output will be maintained at about 400V. Then this voltage will be input of the single-phase full-bridge inverter. Ds is a continuous current diode, and C is the output ripple capacitor which can absorb voltage spike and output stable voltage.

The single-phase full-bridge inverter is adopted in the UPS system, whose circuit structure is shown in Fig.3. The inverter can complete inversion of DC to AC. DSP will control the IGBT switches in the inverter though the drive circuit. At last, harmonics will be filtered out, and the voltage, frequency and waveform of AC will be stable. When the discharge circuit works, in the first half of the cycle, IGBT Q1 and Q4 will be controlled by the SPWM wave which is outputted to the inverter, and IGBT Q2 and Q3 will be disconnected. In the second half of the cycle, IGBT Q2 and Q3 will be controlled by the SPWM wave, and IGBT Q1 and Q4 will be disconnected. Then the AC output of the inverter can be controlled by the SPWM wave.

![Figure 3. Discharge circuit with inverter](image)

In the UPS system, the method of double closed loop compound control is applied in the control of inverter, which is shown in Fig.4. The difference between the given voltage and the voltage of load be detected will be output to the current loop though the voltage PI controller. In the current loop, the output of the voltage PI controller will compared with the inductor current. At last, its difference will be the SPWM wave to control the on-off time of IGBT switches, and the output of the
UPS system can be controlled. The simulation results show that this control method can control the output of AC successfully. And this control method not only has very good dynamic performance but also ensures that the discharge circuit works stably.

![Figure 4. Inverter system block diagram with double closed-loop control](image1)

![Figure 5. Discharge circuit simulation model of the UPS system](image2)

The inverter discharge circuit is simulated by the SIMULINK module of MATLAB, whose simulation model [1,8] is shown in Fig.5. The simulation parameters are: DC bus voltage: 400V, rated output voltage: 220V, output frequency: 50Hz, switch frequency: 3000Hz, filter inductance: 1mH, filter capacitor: 60mF, transmitter equivalent resistance: 6Ω, rated output power: 20KVA. Simulation result is shown in Fig.6. As the double PI closed loop control scheme of voltage and current is adopted, the output voltage’s error can be very small, the control system’s dynamic response is also very fast, and dynamic time is very short. Simulation result reflects that the UPS system can meet the need of the transmitter easily.

![Figure 6. Simulation result of discharge circuit](image3)

5. Overall design of the UPS system’s software based on DSP
The UPS system’s software is realized based on the hardware platform of DSP. The charge and discharge control flow uses sequential structure, which consists of an infinite loop main program and
several interrupt subroutines. To improve real-time performance, the interrupt subroutines only do the simple work (such as charging or discharge process control subroutine), and the majority of the work (such as command processing, calculation) is done by the main program. The main program loops through the flags to determine whether interruptions have occurred and whether the corresponding treatment is needed. The flow chart of the main program design [1, 2, 3, 6] is shown in Figure 7.

![Figure 7. The main program flow chart of the UPS system](image)

After the program starts, the initialization of the system is carried out first, which includes the initial settings of system control, I/O, A/D, PWM, SPWM, interrupt vector table, timer, etc. Then the interrupts at all levels are turned on for system self-check. The self-check includes whether the battery pack’s positive and negative pole is reversal connected, whether the charging and discharging is over-voltage, over-current, whether the battery is over-temperature, etc. If the fault is found by self-check, the system will be reset and checked. The cause of the malfunction will be displayed on the LCD and alarm signal will be sent out at the same time. After the self-test is passed, AD sampling and digital filtering will be implemented to judge whether the ship power is normal, whether it meets the conditions of charging or discharging, etc. Finally, the system comes into the main program, and waits for interruption to occur, executes corresponding interruption subroutines, realizes the functions of each functional module, and finally outputs precise phase-shifted PWM wave for battery charging, outputs PWM wave to Boost circuit, and outputs SPWM wave to drive the inverter. If overvoltage, overcurrent and other faults are detected in the circuit, PWM wave will be blocked in time to protect the system.

6. Conclusion

In the paper, a UPS system is designed for the high power transmitter of ship-borne radar. This paper briefly introduces the overall design of the power supply system, the design of storage battery, charge and discharge scheme and the overall design of charge and discharge system software based on DSP. SIMULINK is used to simulate the discharge circuit, and the feasibility of the discharge scheme is verified. The UPS system designed in this paper has reasonable overall structure and strong applicability. It can provide stable backup power for radar’s transmitter, which can improve the reliability of radar’s transmitter. The design concept has reference significance, and can be widely used.

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