Power supply system design and build for Antarctica telescope

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ABSTRACT

Currently, more and more telescopes were built and installed in Dome A of Antarctic. The telescopes are remote controlled, unattended operation due to Dome A's environment. These telescopes must be work successfully at least one year without any failure. According to past experience, the power supply system is the weakest point in whole system. The telescopes have to stop if the power system have a problem, even a minor problem. So the high requirement for power supply system are presented. The requirement include high reliability, the self-diagnosis and perfect monitor system. Furthermore, the optic telescope only can work at night. The power source mainly relay on diesel engine. To protect the Antarctic environment and increase the life of engines. The power capacity is limited during observation. So it need the power supply system must be high power factor, high efficient. To meet these requirement, one power supply system was design and built for Antarctic telescope. The power supply system have the following features. First, we give priority to achieve high reliability. The reliability of power system was calculated and the redundant system is designed to make sure that the spare one can be work immediately when some parts have problems. Second, the perfect monitor system was designed to monitor the voltage, current, power and power factor for each power channel. The status of power supply system can be acquired by internet continuously. All the status will be logged in main computer for future analysis. Third, the PFC (Power Factor Correction) technology was used in power supply system. This technology can dramatically increase the power factor, especially in high power situation. The DC-DC inverter instead of AC-DC inverter was used for different voltage level to increase the efficient of power supply.

Keywords: Power supply, reliability, PFC, FMEA, Antarctic

1. INTRODUCTION

Dome A (80° 25'01" south, 77° 06'58" east, 4093m elevation) lies at the highest point of Antarctic plateau. The meteorological and site testing result show that Dome A is an excellent astronomical observatory site due to its good seeing, low boundary layer, low temperature, dry atmosphere, polar night, etc[1]. The Dome A was first visited via overland traverse in 2005. The first astronomical facilities, CSTAR (Chinese Small Telescope Array) and site-testing instruments, were installed in Dome A. Currently, the main telescopes in Dome A are two AST3(Antarctic Survey Telescope) telescopes, which primary mirror is 680mm and the FOV is 4.14°. The main science object is to research supernova, dark energy and exploring extra-solar planets.

The telescopes in Dome A must be designed to run unattended for periods of up to one year because there is no permanently manned station in there. A major hurdle of unattended telescopes is the ability to provide power in a reliable and consistent way because the telescopes are intolerant to the slightest interruptions of power and are highly sensitive to power quality variations. Moreover, the efficiency of power system is one of the most important considerations in the design stage because of the limited power capacity. The total power consumption of one telescope is limited by the capacity of diesel engine, which the maximum output of one engine is 1.5kW. The power consumption of supporting system, such as communication system, thermal control system and computers, nearly is greater than 500W. So the power consumption of one telescope must be less than 1.0kW.

Therefore, the main objective of work described in this paper was to design, build and test an efficient and reliability power system. Section 2 describes design of power system. The PFC is presented in Section 3 to increase the efficient. Reliability analysis is presented in Section 4. Test result can be found in Section 5.

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2. POWER SUPPLY DESIGN

2.1 POWER SOURCES IN DOME A

The telescopes in Dome A are powered from PLATO-A (PLATeau Observatory for Dome Argus) which developed by UNSW (University of New South Wales). PLATO-A can provide continuous power, communication and thermal management. It consists of two separate modules: the engine module which house five sets of Hatz 1B30 engines and instrument module that house all electronics, control and communication system [4]. The maximum engine output power is 1.5kW. The power sources include 6000 liter fuel, solar and wind. The solar panel can provide 1.0kW power in summer time. Dome A experiences an ~130 day continuous period of darkness. During the winter time, there is no solar power available, the fuel is the only power source. Figure 1 (left) shows the layout of facilities in Dome A. From the diagram it can be seen that all astronomical instruments were installed around instrument module to make sure that the connection cable between facilities and instrument module is short. It can reduce the power loss and signal loss. Figure 1(right) shows the schematic of power system of PLATO-A. Electrical power from all power sources are converted to 120VDC bus. Then the 120VDC is converted to 230VAC and 24VDC separately and distributed to all instruments.

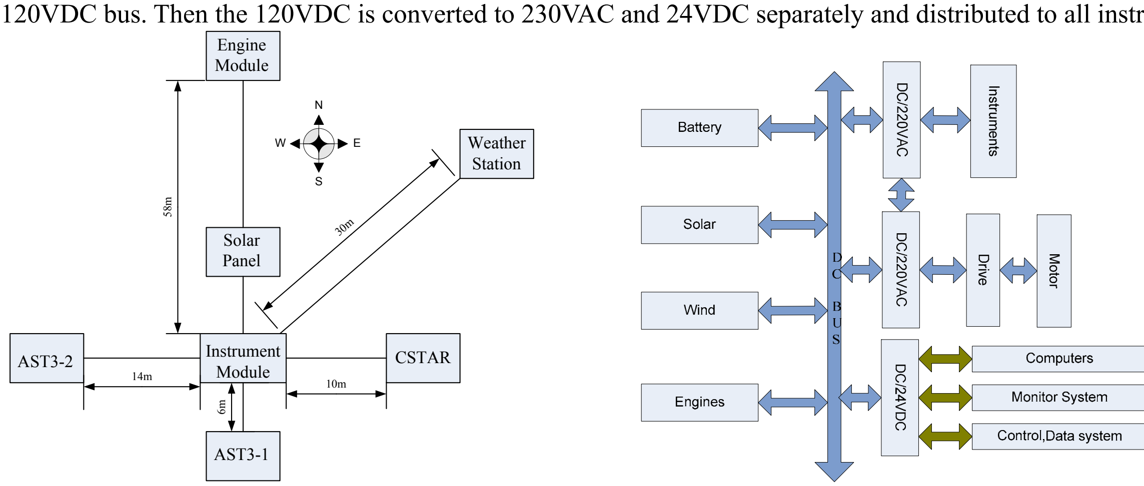

Figure 1. Power sources in Dome A

The telescopes include many kinds of subsystem, such as motors, cameras, computers, thermal control system. The power consumption of all subsystems is listed in table 1. From table 1, it can be seen that the total power consumption of one telescope is 330W and it is not a big consumption. At the beginning of design, the power factor and efficiency of power system was not caused enough attention and both parameters were low. The power factor is 0.7 and the efficiency is 0.85 for the whole power system. The input power consumption is 554VA. It leads to a significant increase in power consumption. It not only wastes the capacity of power system but also increase total fuel consumption. Dome A has strict requirement on environmental protection. So we must take some technology to increase the efficiency of power system.

Voltage	Power(W)	Equipment
24VDC	135	Computer, Motor Driver, Mirror Heater, Focus Motor, Switch, CCD Heater
12VDC	48	Cameras, Cooling Pumps
7VDC~14VDC	24	Encoders Heater
5VDC	3	Decoder board
220VAC	120	Controller, Motor Drivers, GPS Server, Serial Server

Table 1. Power supply requirement of AST3 telescope

2.2 THE POWER SYSTEM DESIGN

The requirements of power supply system are listed below.

(1). The power system must provide many kinds of voltage level, precision and power capacity to different devices.

(2). All devices must be easy connected to power system because the installation time is short on site.

(3).The efficiency and power factor should be high because the power capacity is limited.

(4).The telescopes only can be maintenance once per year. So the high reliability and long life of power supply system is needed to make sure it can work smoothly at least one year.

(5).All modules should be contained in one cabinet because the space is small.
(6).There is no reliable grounding because all devices directly were installed on the surface of snow. So the interference is more seriously than other place.

Base on the above requirement, the specification of power system are listed here. The total power capacity is 500W. The conversion efficiency is greater than 85%. The power factor is greater than 80%. The voltage accuracy of power system is less than 0.1%. The load regulation is ±0.1%. The operation temperature is from -20°C to 45°C. The power also must have the following protection function, such as short, over load, overcurrent and over temperature protection. The design principles are listed below in order to meet the requirement. (1) Redundant design, derating design and avoiding single point failure are applied in power system to improve the reliability. (2) Variety of anti- interference measures are used to improve the stability of power supply system. (3). All devices can be controlled in order to provide a high degree of flexibility. (4). The performance of the power supply system is monitored by remote computers.

The figure 2 shows the whole power system. The power system is divided into 3 parts. The first part is PCS (Power Convert System). Its main task is to convert AC power to DC power. Then the DC power is converted to the specific DC voltage to meet the requirement of each device. To achieve high levels of reliability we developed a system of two DC/DC modules in a dual-redundant configuration, each can meet the power capacity requirement of telescope. The modular-based system is used in PCS design. The modular DC/DC has the following advantage. (1) DC/DC power module uses the advanced manufacturing technology to form a compact small size of the high quality power supply. The system has the advantages of convenient expansion and good maintainability. (2) DC/DC modules integrate the EMI filter. So they have strong immunity to external and internal noise. (3) DC/DC modules have protection function. This can ensure the module work well even if the load failure.

The second part is PSM (Power System Monitor). The main task of PSM is to monitor the performance of the power supply system and transmits the real-time status information to the master computer. Base on this information, the master computer can know exactly the status of power system, diagnose any problems and isolate the faults in order to protect the power system. The voltage, current and temperature were sampled. Two kinds of current sample methods are used in current sample. The hall current sensor is used to sample the AC current and resistors are used to sample the DC current.

The third part is PDU (Power Distribution Unit). The function of PDU is to distribute power to the corresponding electrical equipment according to logic program. This part is also used to isolate the failure devices. The relays are used to switch the devices on or off. Two independent relay modules are used for PDU for high reliability.

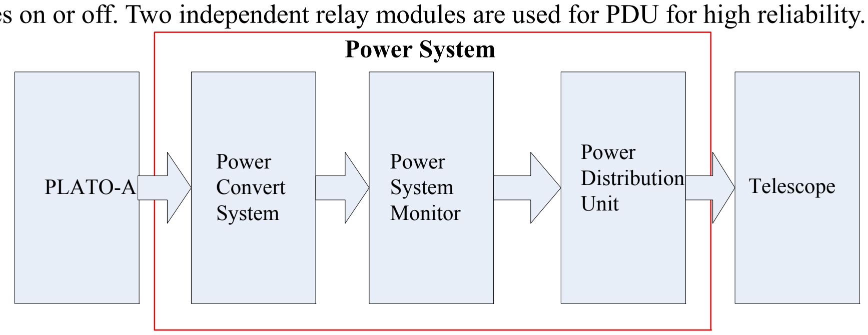

Figure 2. The power system design

3. THE PFC CORRECTION

Many parts of telescope, such as transformer, motor and power modules, are based on electromagnetic induction principle. The alternative magnetic field must be established in order to carry out energy conversion and transmission. The process that energy transformed from one form to other forms consumes the capacity of power system. The power factor, which is the ratio of the effective power divided by the total power consumption, should be high in order to achieve high utility ratio of power capacity.

From above analysis in section 2.1, we can see that the power factor is too low. So we must increase the power factor. PFC (Power Factor Correction) is a technology to increase the power factor of power system. There are two types of PFC, passive PFC and active PFC. Figure 3 is the schematic of active PFC.

In order to increase the power factor of whole power system, the active PFC was used in telescope power system building. The power factor of power system increase from 0.67 to 0.80 after the PFC was used. So the total power consumption reduces 65VA. This result can improve the rate of capacity usage of power system.

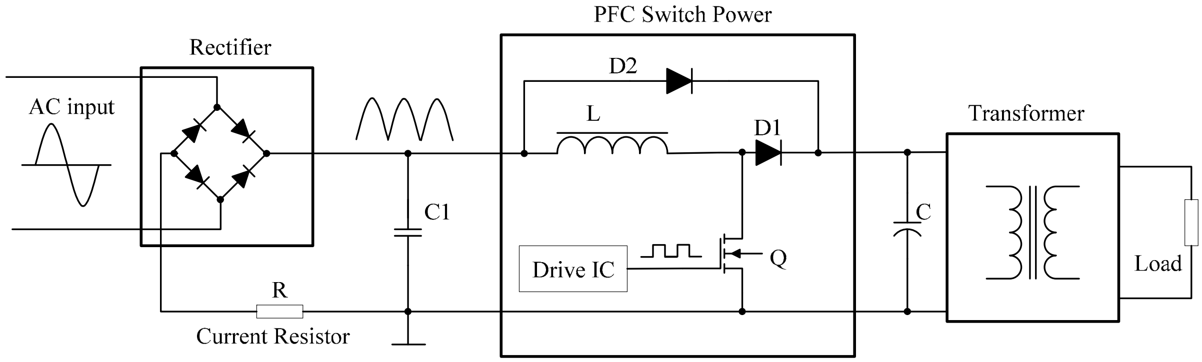

Figure 3. PFC circuit schematic

4. RELIABILITY OF POWER SUPPLY

Product reliability prediction and analysis is important for the product feasibility design, the choice of components, product maintenance strategy. According to the past decade experience in Antarctic telescopes building, the main lessons learned are that the power supply system must use proven components, carefully manufacturing process and avoiding single point failure. Many power supply failures are attributable to the communication failure, components failure and interconnection failure.

At the design stage, one systematic, top-down approach was used to control part quality and to predict the reliability of systems. The preferred method is based on stress margin analysis, strength of materials and an understanding of the physics of failure of the materials and structures. Normally, some standard about reliability should be used to control the reliability, such as MIL-HDBK-217. But sometimes MTBF (Mean Time Between Failure) prediction using MIL-HDBK-217 has shown very little correlation to actual field performance [5]. Furthermore, unlike the mass production, the telescope normally is single piece of production. So the most of reliability analysis based on statistics cannot applied to telescope design.

The first step of reliability analysis is to fully understand failure mechanisms. The failure mode and mechanisms were analyzed. The following is a list of failure mechanisms of power system in Antarctic.

Failure source	Effect of failure source
software defection	Some data will be lost.
Temperature	The electrical components and solder joint easy to broken in low temperature. The life of components will decrease and the unstable condition will happen when the temperature is too high.
Interference	There is no true ground because all facilities were directly installed on the surface of snow. Sometimes the devices work unstable under interference.
Conductor breakage	The interface will disconnection and lead the signal stop.
Component random failure	The devices will stop working or unstable.

Table 2. The failure mode

In order to achieve high reliability of power system, the FMEA (Failure Modes and Effects Analysis) was used in power system building. FMEA is to identify potential failures, assess their impact, and develop mitigation strategies in the design stage [6]. Currently, FMEA is widely used in many fields that require high reliability. The table 3 is the FMEA analysis chart for the power system based on the module subsystem. The severity, occurrence and detection scores are ranged from 1 to 10. The RPN (Risk priority number, RPN=Severity*Occurrence*Detection) is used to quantify the risk. From table 3, we can see that the highest RPN is 24VDC power failure. So the additional methods must be presented to avoid this failure. The following methods were applied in power system building. (1) Two independent 24VDC power modules were used to provide 24VDC. The capacity of each of module can fulfill all power consumption. (2) The third power source that from PLATO-A is available if necessary. (3) The cooling fan is used to control the temperature of 24VDC power modules so that the lifetime of module can be guaranteed. (4) All the modules that need 24VDC have short circuit protection.

Item	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Cause	Occurrence	Current Design Controls	Detection	RPN	Recommended Actions
1	24VDC power failure	All the motor drives and computers will stop working	10	The load is short. The fuse is broken. The temperature is too high.	2	Each device have it s short protection. Redundant design.	4	80	
2	The current sample resistors were broken	The power will open and related device stop working	5	The physical failure. The temperature is too high.	3	The resistors keep protection. Two sample resistors	2	30	Noncontact current sensors are used
3	The temperature is too high.	The powers stop work for a while.	2	The output current is too high. The heat dissipation is low.	2	Power capacity is enough. The fans are used.	1	4	
4	The output relay malfunction	Some devices can not be controlled.	5	The relay is broken. The communication is failure.	1	Redundant design.	4	20	
5	The input current measurement failure	The status of some devices will not know.	1	The current sensor doesn't work. Some devices' load bypass this sensor	1	Wiring check.	4	4	

Table 3. FMEA analysis chart

5. EXPERIMENTAL TEST RESULTS

The main objective of power system test is to analyze the parameters and the corresponding failure mode and failure mechanism under the environmental stress and working stress. For electronic products, the failure mechanism can be divided into two kinds of failure modes. The first failure mode is overstress failure and normally is caused by excessive stress. The other failure mode is loss type failure and usually is caused by the stress accumulation. According to the reliability bathtub curve, these early failures can be eliminated by aging test and factory test.

The whole tests include lab test and reliability test. The lab test includes static test and dynamic test. The static test is to prevent all the components on the PCB from badly or mistaken soldered by optical check and impedance measurement. The dynamic test is to power on the whole system and measure the voltage and current to make sure the voltage level, ripple, waveform and timing remain within specification. The reliability test is to put the power system in cabinet under full load condition. The high temperature of cabinet is set to 35°C and low temperature is set to -20°C. The duration of reliability test is one week. During the reliability test, the voltage, temperature, ripple were measured to make sure the power system work well. The aging test is to run power system in room temperature under full load condition. The aging test continuous run until the power system was delivered to Antarctic. The figure 4(right) is temperature picture during aging test.

The power system will be updated if any abnormal points were found during test. For example, the temperature of the sample resistor for 24VDC output current reach to 95°C during load test. The high temperature of resistor may reduce the life of resistor because the life of component will be half after the temperature of component increase 10 degrees. So the additional sample resistor was added to share the output current. The temperature of resistor reduces from 95°C to 40°C after this modification.

Figure 4. Power system and temperature picture

6. CONCLUSION AND FUTURE WORK

The power system worked very well since it was installed in Antarctic. The power factor increase from 0.67 to 0.80 after the PFC was used. The total power consumption reduces 65VA. The telescopes in Dome A must be designed to run unattended for periods of up to one year because there is no permanently manned station in there. The reliability is primary factor in power system design. The FMEA process was completed in the early design and enhanced the reliability of the system. The lab test and aging test are completed in order to confirm the specification and increase the reliability. The result shows that the power system fulfills the requirement of telescope in Antarctic.

Continuous improvement process is still ongoing to improve the quality and reliability of power system. The future plan includes that all modules are integrated into one circuit board to increase the reliability and reduce the interference. The current sample method will be replaced by noncontact hall components. More relays will be used to the power system to provide a high degree of flexibility.

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