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A Design and Implementation of Power Transfer Equipment Based on Fault Diagnostics in System Level

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This paper presents a design and implementation of a certain automatic power transfer equipment adopted by a power supply system serving for nuclear industry. An integrated approach that employs techniques from engineering disciplines including failure analysis based on usage history, advanced fault detection, sensor-based condition monitoring, and power electronic control was used. The function of fast switching-over between the master and standby power supply units as faults occur in power supply system level was implemented. After the probation period of the equipment, it showed that the uninterrupted power supply function and operational reliability of the whole power supply system were well enhanced.

1. Introduction

Power supply system plays an important part in nuclear industry in order to provide electrical power for specific loads such as centrifuges etc.. Their faults and failures will cause operational downtime to loads and the whole system, which will lead to severe economic loss and even casualties. Therefore, power transfer equipments are widely used to insure an uninterrupted capacity of power supplying as soon as the faults or failures happen to power supply system. In this paper, we present a design scheme of some automatic power transfer equipment, whose main function is to switch the power supplies between the master and the standby units, which are AC (alternation current) 380V/100HZ or 380V/50Hz. The automatic switching-over method guarantees the uninterrupted power source input to loads.

2. The approach to fault diagnosis

The adopted approach to fault diagnosis is illustrated in Figure 1, which is a basic technological process to conduct fault diagnosis to a system. It involves fault feature parameter identification, baseline establishment and verification, advanced detection technology, condition monitoring, data manipulation, and diagnosis scheme development (Shi, 2011).

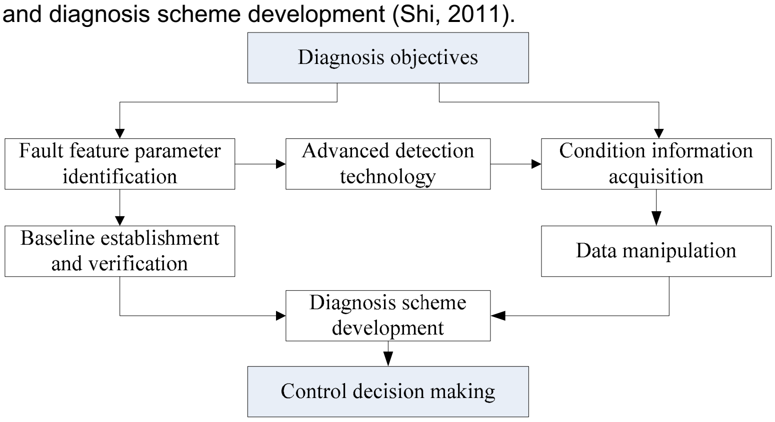

Figure 1: an approach to fault diagnosis

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A fault feature parameter is a data event or trend that signifies fault. The indication of these parameters is usually a variation of a measurable variable. Fault feature parameters' identification is usually carried out by analyzing the historical operational data, such as performance parameters selected by reviewing service and maintenance records and analyzing potential fault modes and failure mechanisms (Zhang et al., 2009). The reliability analysis methods such as FMEA can also be applied (Luo et al., 2011).
A performance baseline is a fault criterion built according to operational conditions and requirements of system performance. With respect to a single fault feature parameter, baseline characterizations are indicated by tolerance, threshold or distribution. Baseline determination also proceeds with identification of relationships between multiple fault feature parameters, calculation of data features that could represent multiple parameters and establishment of the baseline by training data. Experiments or computer simulations need to verify the repeatability of baseline characterization (Zhang et al., 2009).
Based on reasonable advanced detection technology, operational condition information is acquired as a form of parameter data. Data manipulation transfers the acquired data to some forms that can indicate feature of faults by using signal processing technologies, including signal transformation and conversion, such as amplification, attenuation, filtering, rectification, statistic analysis, frequency analysis, etc..
A diagnosis scheme is developed to identify abnormal situations, which may be also impending in an on-line environment. Algorithms or rules are used to determine anomalies and furthermore predict faults or failures.
By means of the diagnosis result, people make control decision like condition-based maintenance and protection.

3. Function and structure design of the power transfer equipment

3.1 Function requirement analysis

By using the approach described in section 2, a certain power transfer equipment was designed, which can monitor the condition of power supply system, detect the faults or failures, process the fault data, identify the anomalies and perform switch-over control, condition indication and protection to insure that the loads have uninterrupted power source and safety.

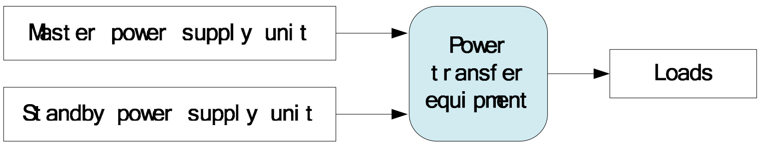


Figure 2: relationship of power supply system, power transfer equipment and loads

Relationship of power supply system, power transfer equipment and loads is displayed in Figure 2. Input of the designed power transfer is a three-phase four-wire alternating current (AC) with a frequency as 100 Hz (±2%) or 50 Hz (±2%) from master and standby power supply units. Rated phase current of each power supply unit is 100 amperes (use A for short in the remainder of this paper). The loading capacity of the master unit is prior to the standby one.
There are two types of switch-over requirements, automatic and manual ones. Connection devices between the power transfer equipment and power supplies are SCSs (short for silicon controlled switches) driven by automatic controlling signals sent by the power transfer equipment and manual knife switches. They are both executive devices of switch-over.

3.2 Structure requirement analysis

In order to meet the requirements of function and maintenance, structure design of power transfer equipment is based on a modularization method. It consists of electronic switch (SCS) module, knife switch module, control circuit module, control power and detection circuit module, signal transfer circuit module, and electronic switch final stage circuit module.

3.3 Function and structure framework of the power transfer equipment

Framework of the power transfer equipment was shown in Figure 3.
Knife switch module was used to realize the manual switch-over function. When the master power supply unit is on load and the standby is normally operating, it can be manually and easily switched to the standby. It is the same in the opposite way.
Electronic switch module carries out the automatic switch-over function. Two anti-parallel SCSs are assembled in each phase of three-phase AC.

An electronic switch final stage circuit is also assigned in each phase of the input power. It isolates and amplifies the control signals, drive pulses from control circuit so as to generate the drive signals for SCSs. In addition, they detect and transfer the current in SCSs to identify the condition of SCSs.
Control circuit is the core of the power transfer equipment. By processing all the detection results, it determines the operating condition of power supply system, SCSs and loads, and then performs switch-over, condition indication and protection functions.
The role of control power and detection circuit is to produce the power supply for inside devices and components in the power transfer equipment, and to detect the input and output voltage for the power transfer equipment.
Signal transfer circuit is designed as a mother board to connect the electronic switch final stage circuit, control circuit, and control power and detection circuit all together.

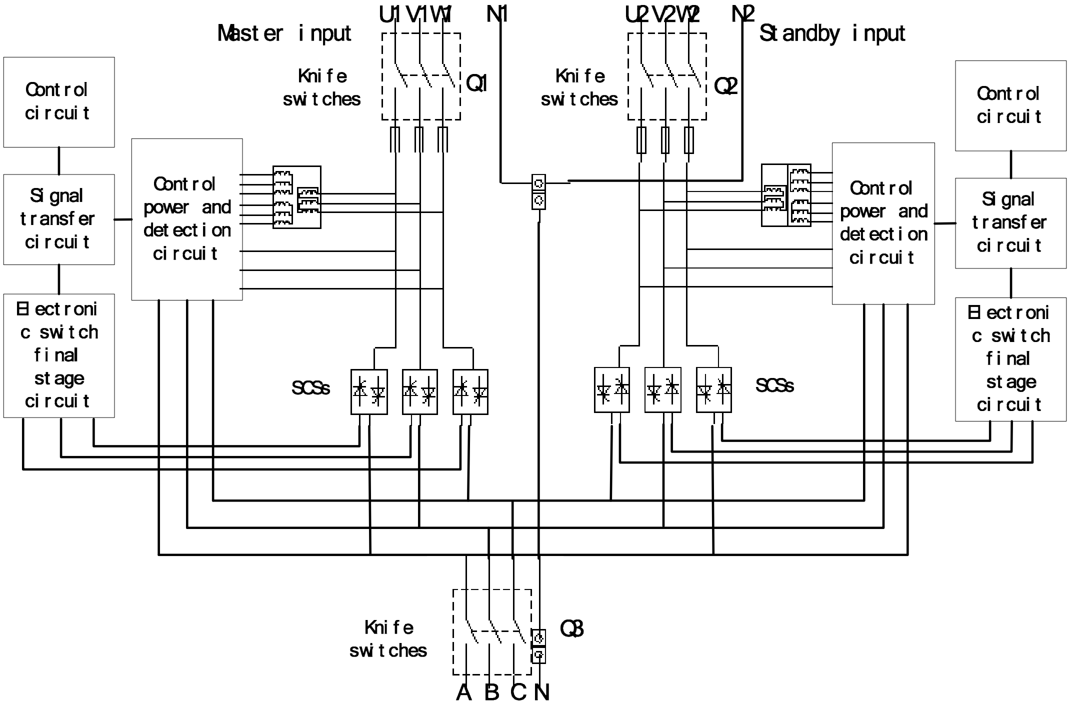


Figure 3: function and structure framework of the power transfer equipment

Switch-over control, condition indication and protection are the main functions of the designed power supply transfer equipment. The master and the standby power source going through the knife switches are separately connected to SCSs. As soon as faults occur, the detection devices send the signals to control circuit. The control circuit generates switch-over order to the electronic switch final stage circuit to block the drive pulse of SCSs, which switches off the SCSs in operating state. One of the power supplies is cut off. After a time-delay, the drive pulse of the originally off-state SCSs is released to connect the alternative power supply unit to loads.

4. Detailed design of the power transfer equipment

4.1 Fault feature parameter identification and baseline establishment

Fault modes directly related to switch-over control, condition indication and protection need to be detected by the power transfer equipment. Firstly, according to usage conditions, there are some faults of the power supply system that affect the loads badly or cause the downtime of the loads. Meanwhile, the condition of loads affects the power supply system in reverse when the latter is supporting the former. Consequently, input voltage out-of-tolerance, overload, load short–circuit and output open-circuit are the fault modes chosen to be detected. Secondly, the power transfer equipment should be reliable and durable. Therefore, there are three fault modes, SCS breakdown, SCS off-line and SCS without-drive-pulse chosen to be detected, due to the important switch-over performance function of SCSs. Table 1 gives fault feature parameters and quantitive and quanlitative corresponding fault criterions of the fault modes mentioned above.

Table 1: Fault feature parameter and corresponding fault criterion

Fault mode	Fault feature parameter	Fault criterion
input voltage out-of-tolerance	voltage of the master and standby power supplies that input the power transfer equipment	rated voltage ± 20%
overload or load short-circuit	output current of SCSs in each phase	threshold of both the duration (≥ 70 ms) and amplitude(≥ 150 A)
output open-circuit	output voltage of the power transfer equipment	having it or not
SCS breakdown	current of each SCS	threshold of inverse current of SCS in operating state and forward current of off-state SCS (1 A)
SCS off-line	filtered output voltage of SCSs in each phase	in the condition of three-phase balance non-Y- load, having it or not in the condition of three-phase balance load of other types, the duration of low level voltage after comparison
SCS without –drive-pulse	drive pulse	having it or not

4.2 Detection techniques

The detection techniques of all the fault modes (in Table 1) are presented below.

For “input voltage out-of-tolerance”, the detection method is displayed in Figure 4. It shows a process of one phase of input voltages from power supplies. The absolute value of input voltage is filtered by a second-order LPF (Low-pass filter) and then a first order LPF in order to get the effective value of input voltage. After the process of maximum and minimum circuit, the maximum and minimum value of the effective value of the input voltage are transmitted to comparison circuit to determine if it is out of tolerance of rated voltage ± 20%. A high level signal will be sent out when this fault mode occurs.

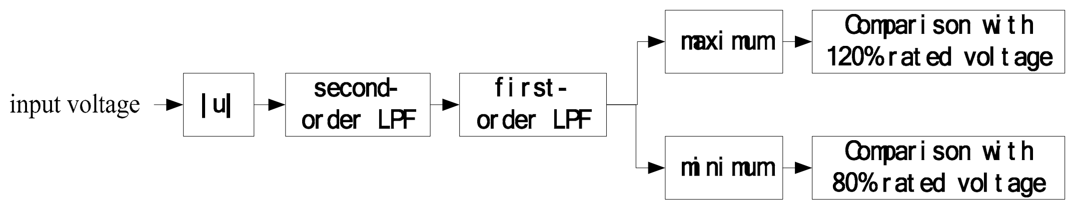


Figure 4: detection method for “input voltage out-of-tolerance”

For “overload or load short-circuit”, the detection method is that online testing data of output current of SCSs in each phase is compared with standard values in both the time and amplitude range. Hall current sensor is used to obtain the output current data. After transferred and filtered, it was sent to an over-load comparison circuit. A high level signal means this fault mode occurs.

For “output open-circuit”, the detection method is displayed in Figure 5. It is shows only one of three phase s as well. The input voltage processing part comes from Figure 4. The output voltage is compared with the input voltage. In comparison circuit, the result of comparison is generated as a form of pulse signal, when the duration of high level signal of output is less than 70% of the input one in each cycle, it means this fault occurs.

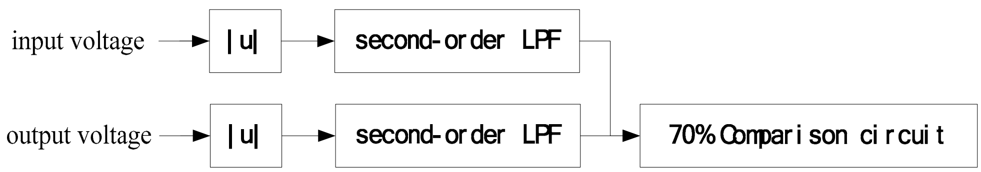
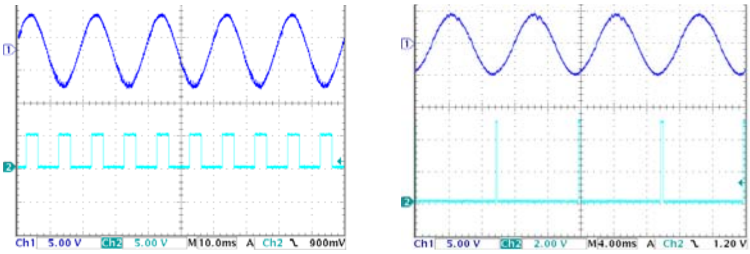


Figure 5: detection method for “output open-circuit”

For “SCS breakdown”, current of each SCS is detected by high-accuracy Hall current sensor and filtered by LC-filter to avoid false alarm due to a sudden uploading or unloading. The current signal from Hall sensor is transmitted, filtered, amplified and then sent to a comparison circuit to indentify if it is lower than 1 A.

For “SCS off-line”, the situation is more complicated than others. There two condition need to be respectively considered. In the condition of three-phase balance non-Y- load, the output voltage of SCSs in each phase is filtered by a greater strength LFP , and then sent to a comparison circuit that identify if the voltage is lower than the threshold. On the other hand, in the condition of three-phase balance load of other types, the output voltage of SCSs in each phase is filtered by a smaller strength LFP, and then sent to a pulse comparison circuit. Figure 6. (a) shows the condition of none SCS off-line. When the output voltage is normal, the pulse comparison circuit gives a good pulse wave after comparing the output voltage with its threshold. The opposite condition is shown in (b). When the output voltage is lower than the threshold, there will be a longer duration of low level signal after processed by the pulse comparison circuit. For example, if the power supply is in 50 Hz and the duration of low level signal in each cycle is longer than 10 ms, the fault mode, SCS off-line occurs.



(a) (b)

Figure 6: detection method for “SCS off-line”

For “SCS without-drive-pulse”, this fault mode is identified directly by testing the drive pulse signal with the control core device, CPLD, which will be introduced in section 4.3.

4.3 Implementation of fault diagnosis and control decision making

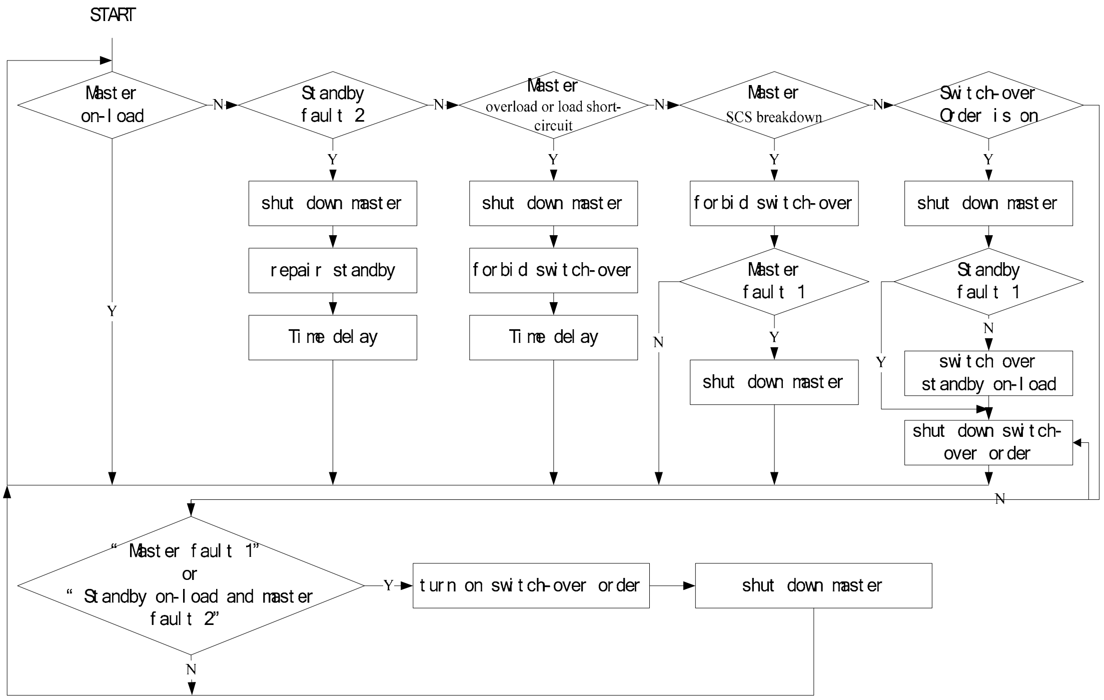


Figure 7: control flow chart of switch-over and protection

Control circuit takes over the signals from advanced sensors that transfer the signals shown in Table 1 and performs detection presented in 4.2. In this circuit, a Complex Programmable Logic Device, i.e., CPLD was used to process the detection results and generate switch-over, condition indication and protection signal. The commercial model number of CPLD adopted is MAX3256ATC144 - C10, which can be used to realize a digital system with programming. This paper chose VHDL (Very-High-Speed Integrated Circuit Hardware Description Language) to describe and simulate the structure, behaviour, function and interface of the digital parts of control circuit, implementing diagnosis and control decision making.
Control circuit consists of CPLD, peripheral circuit, communication interface circuit, fault detection circuit and control drive-pulse generating circuit. Inside CPLD, fault data manipulation, switch-over signal generating, protection signal generating and condition indication signal generating are programmed.
The fault modes are classified by two types in control decision. One type is that causes switch-over between the master and the standby power supply unit, including input voltage out-of-tolerance, SCS off-line, output open-circuit and SCS without- drive-pulse. They are collectively called as “fault1” in the control flow. Another type that causes repair work to the power transfer equipment, including SCS breakdown and overload or load short-circuit. They are collectively called as “fault 2”. The control flow chart of switch-over and protection function is illustrated in Figure 7. The condition indication signals are sent out by the control circuit when faults occur and switch-over order turned on. It is implemented with various indicator lights in the power transfer equipment.

5. Condition of probation and future work

This paper provides theories and techniques of a design and implementation of a certain power transfer equipment. Time for switch-over is less than 15 ms for 50 Hz power supplies and less than 10 ms for 100 Hz power supplies. That not only meets the requirement of user but also reaches a very high technical level in the same kind equipment. The uninterrupted power supply function and reliability of the whole power supply system were well enhanced. Figure 8 gives examples of the switch-over function. With a 100 Hz power supply system, (a) displays the output voltage wave of the power transfer equipment when SCS off-line occurred in the master unit and the power source was switched to the standby one. With a 50 Hz power supply system, (b) displays the output voltage and current wave of the power transfer equipment when input voltage out-of-tolerance occurred in the master unit and the power source was switched to the standby one.

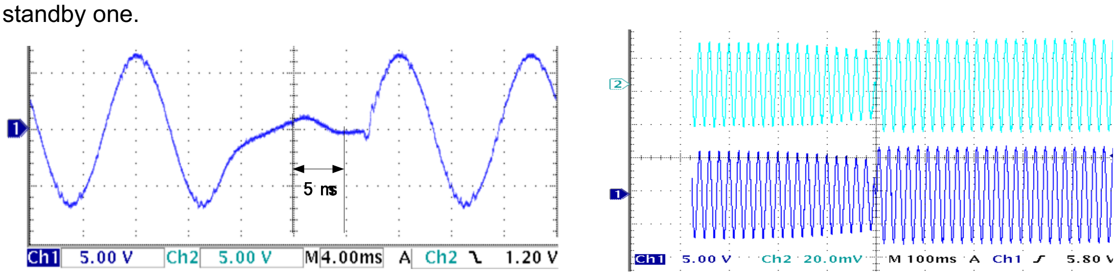


Figure 8: examples of switch-over function of the power transfer equipment

There is still improvement work needed to do in order to decrease false alarms and switch-over in the condition of a sudden uploading or unloading. The switch-over performance devices can also be changed due to the failure analysis of SCSs. This will be solved in the future work.

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