Modeling and simulation of loss of power in nuclear power plant

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***Abstract*—This paper presents a model of NPP power system. The model is built from power system network to nuclear auxiliary system designed for safety function. Simulation result of loss of offsite power incident with this model shows the potential risk on nuclear safety and provides input for analysis during unit commission and maintenance.**

***Index Terms*—Nuclear power, Modeling, simulation, loss of power, nuclear safety**

I POWER AS SUPPORTING FUNCTION FOR NUCLEAR SAFETY

THE different from a fossil fuel power plant is that the reactor must be cooled all the time, even a certain period after the reactor has been shut down because the reactor will keep producing large remnant heat. The cooling circulation through the reactor must keep running by power.

Nuclear power plants use multiple power sources, including connection to offsite grids, function of house loading, onsite diesel generators and battery array. These configurations have supported nuclear safety for a long time.

A. Nuclear power system design principle

Power source of plant auxiliaries is normally supplied by turbine generator or main offsite grid. When unit source is unavailable, unit will transfer to backup source. If the backup source is unavailable, unit will transfer to onsite power, diesel and battery.

Plant auxiliaries are cataloged by its function, safety related, main equipment, unit common. They are supplied and backed up by different level of above sources.

B. Evolution in 3rd generation nuclear

--First, uninterrupted switch over between sources

The functional blocks of essential plant power changeover are divided into fault trigger, action execution, redundant channel and other, which is to realize the precision, rapidity and reliability of the changeover function. The fast switch device (COD) is the executive mechanism of changeover between ANT and AST, through GPA, DCS and LG*, the centralized management of essential plant power changeover is realized. That is to say, the changeover is triggered by GPA fault signal, COD responds, and DCS acts as the backup channel for signal triggering to increase the redundancy of switching. The COD flow chart of a power plant is shown in figure 1.

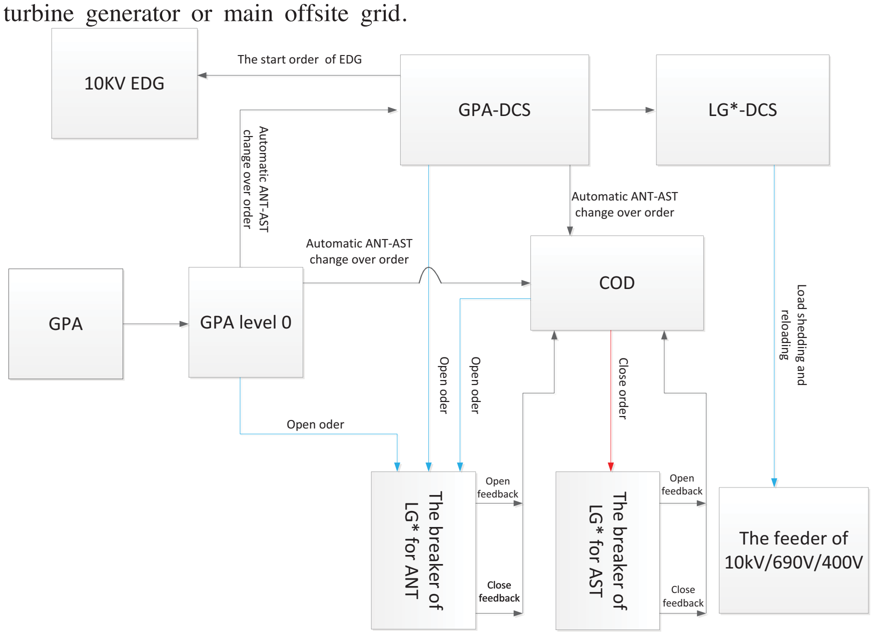

Fig.1 The flow draw of COD

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--Second, cross connection between trains

In order to meet the downstream demand in the maintenance process of distribution system, cross power supply of distribution systems can be realized. Due to the capacity requirement of power supply, cross power supply only meets the power demand of some safety level equipment. The operation mode is manual operation to avoid the wrong synchronization of different power sources. The cross power supply diagram of a power plant is shown in Figure 2.

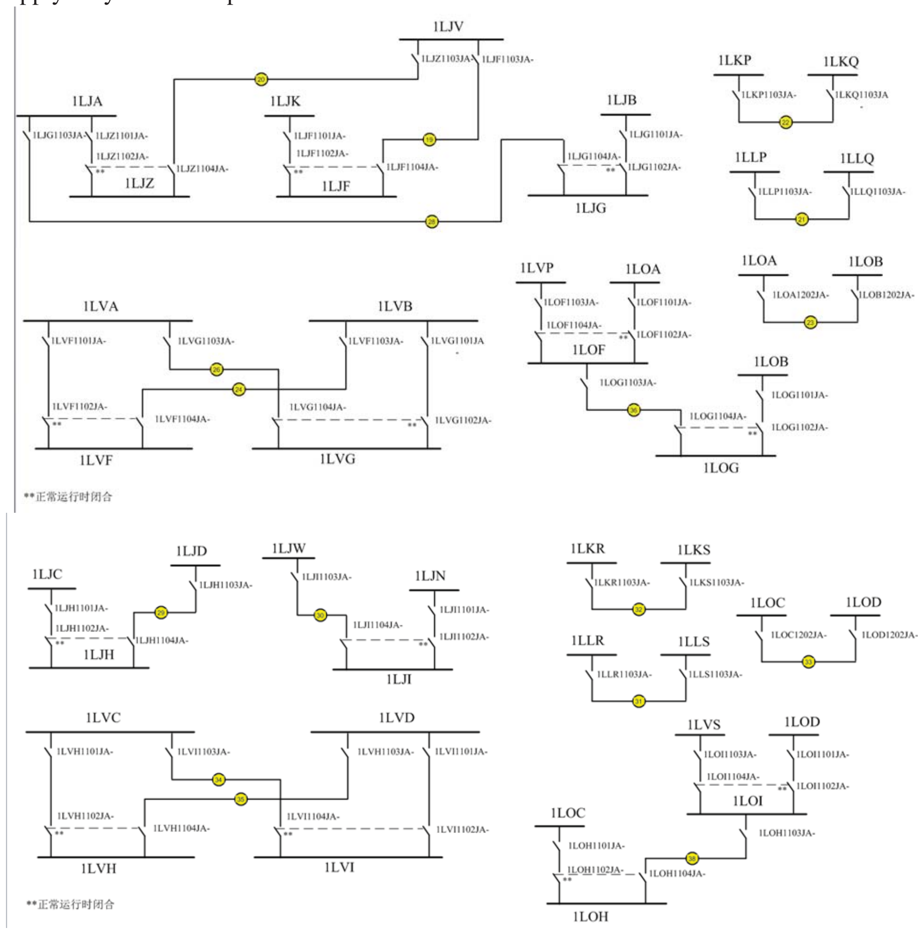

Fig. 2 The flow draw of Cross connection
LV*/LJ*/LO* are LV switchboard

--Third, new station blackout power sources

The black start power supply (SBO), two independent diesel generators, is designed to mitigate the consequences of station blackout (loss of offsite power + loss of the main generator + all emergency diesel generators failure) （DEC-A）. Its characteristic is that it can start manually in a certain time without the control loop of the diesel engine, and supply the power to the safety level equipment of the nuclear power plant, so as to stabilize the plant. The black start power supply diagram of a power plant is shown in figure 3.

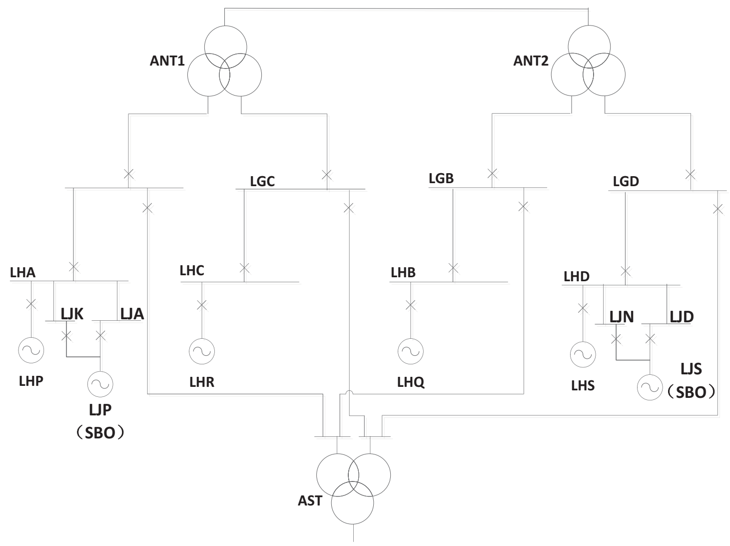

Fig.3 The electric draw of blackout power sources
LGA/LGB/LGC/LGD/LHA/LHB/LHC/LHD are MV switchboard；LHP/Q/R/S are EDG；LJA/K/D/N are LV switchboard；
LJP/LJS are blackout power sources(SBO)

Even units with full applied of passive safety function, it also requires multiple level power for preferred active safety function and extension of limited passive function duration.

II MODELING OF NUCLEAR POWER SYSTEM

In view of the defects of man-made analysis over power loss, a method and system for identifying the power loss of the nuclear power plant is introduced. It can detect the availability of the power supply of the safety system and the function of the safety system equipment, so that the power loss accident can be forecasted effectively. Furthermore, through the establishment of mathematical model and formula, the mathematical method for failure analysis is provided to calculate the consequence of overlapped accidents and loss of power under different unit states.

A. *Safety function to system*

The safety function of nuclear power plant is mainly used to protect the integrity of three safety barriers (that is, fuel cladding, primary circuit pressure boundary and containment), and then realize the functions of reactivity control, core heat derivation, radioactive material containment, and so on. A power loss accident identification method for a nuclear power plant comprises the following steps: detecting whether the power source of the safety system equipment of each nuclear power plant is available; if the power source is available, analyzing whether the function of the safety system equipment of the nuclear power plant is available or not; If the equipment functions of each nuclear power plant safety system are available, it can be judged that no power loss occurred in the nuclear power unit.

--First, reactivity control

Rod control: the main function of the reactor rod control system is to control, supervise and restrict nuclear power plant reactors.

Chemical control: the main cooling loop of the nuclear power plant is the coolant in the primary loop, which acts as moderator and reflector at the same time, and controls the reactivity with boric acid solution.

Core instruments: the main cooling loop of the nuclear power plant is the coolant in the primary loop, which acts as moderator and reflector at the same time, and controls the reactivity with boric acid solution.

--Second, reactor cooling

Main cooling loop: the main function is to circulate the coolant of the first loop of the nuclear power plant, so that the heat generated by the nuclear fission in the core is transmitted to the second loop through the steam generator, and the core is cooled at the same time to prevent the burning or destruction of the fuel element.

Safety injection: the main function of the safety injection system is to inject high concentration boric acid into the primary loop when the main cooling loop appears breaches, in order to make up water or to flood the core of the reactor. Or when the secondary steam circuit breaks, inject high concentration boric acid into the primary loop to compensate the positive reactivity of the coolant due to continuous over-cooling, to prevent the core from returning to the criticality.

Components cooling: the main function of the equipment cooling water system is to provide cooling water to all kinds of heat exchangers in the nuclear island and transmit heat load through the essential water system into the sea water. The heat exchangers of this system play the role of preventing uncontrolled release of radioactive fluid into the sea.

Service water: the main function of the essential service water system is to cool down the cooling water system and transfer its heat load to the sea water.

Main and auxiliary feed water: the main water supply system, in the normal operation of the nuclear power plant, extracts water from the deaerator and provides normal water supply to secondary side of steam generator after water going through HP heater. The auxiliary water supply system supplies water to the secondary side of the steam generator as an emergency means in the case of the failure of the main water supply system, so as to maintain a cooling source in the primary loop and remove the residual power of the core.

Safety valves: the safety valve is to restrict the system from exceeding the safety limit. For example, the pressurizer safety valve restricts the pressure rise of the primary loop, and automatically opens to release pressure in case of over pressure.

--Third, containment

Atmosphere condition: the containment ventilation system is mainly to maintain the working environment temperature during the cold shutdown and to reduce the concentration of products generated by gas fission in the containment to allow the personnel to enter into, while maintaining the sub-pressure in the island during the shutdown.

Spray: the spry system is, by spraying of condensing steam, to reduce the pressure and temperature inside the containment to an acceptable level, so as to ensure the integrity of the containment.

B. System to device trains

To meet the safety redundancy requirements of the unit, the equipment of safety system is designed with multiple redundancies and the power supply is supplied by different trains of electrical systems. There are differences in system redundancy between different nuclear power plants.

C. Device to power

The power supply of the nuclear power plant has the characteristics of independence and redundancy, and the safety and operation functions of the plant power equipment under different operating conditions and foreseeable abnormal state are grouped, including the essential bas-bar, backup bus-bar, the common bus- bar and the emergency bus-bar.

Devices are supplied by different power through service network depending on design base: offsite, on site, SBO, mobile.

D. Identification method of Power loss accident in Nuclear Power Plant

--First, identification of power availability

According to the design of the power distribution system used by the nuclear power plant, the formula is created from the safety system equipment of the nuclear power plant to the various kinds of power supply. And the formula D = (B1 & B2 & B3... P1) (B4 & B5 & B6... P2) is used to test whether the power supply of each safety system equipment is available. Where D represents the safety system equipment of a nuclear power plant, P represents power supply, and B represents the distribution switchboard. The calculation result of the formula represents whether the power required for the device is available, and if it's available, it's considered that the device can be transfer to any state, including the state required for nuclear security, and if it is not available, the device can only be in a state of default.

--Second, identification of security system availability

If the power supply mentioned is available, the availability of each safety equipment of nuclear power plant is analyzed.

Specifically, the formula S = D1 & (D2 D3) & D4 is used to analyze the availability of each security system equipment, of which S represents the system function, D represents the state of the security system equipment. For example, if 1 represents valve opening and pump / fan running, 0 represents valve closing, pump / fan tripping, etc.

If the functions of each safety system are available, it is judged that no loss of power has occurred in the nuclear power plant.

According to the requirements of current nuclear safety regulations, design documents and power loss analysis files, should clearly define the necessary functions of nuclear safety systems.

If U represents the safety of nuclear power unit is safe or not, S represents the availability of security system functions, then: U = S1 & (S2 S3) & S4.

To sum up, by detecting the power supply of each safety system equipment of nuclear power plant and the availability of each safety system, we can know whether the nuclear power unit has a power loss accident, which effectively meets the requirements of the safety protection of the nuclear power plant.

III SIMULATION OF LOSS OF POWER

With model above, it is possible to simulate loss power source or switchboard incident. The simulation system has the following 4 modules:

--First, the detection module is used to check whether the power supply and distribution boards of various safety equipment in nuclear power are available.

--Second, the analysis module is used to, in the condition that the detection module detects the power supply being available, analyze whether the functions of the nuclear power plant safety system are available.

--Third, the judgment module is used to know the loss of power failure of the nuclear power unit, in the condition that all nuclear safety system and equipment are available.

--Fourth, the he determination module is used to determine which safety system and equipment need to be detected in accordance with the safety regulations of the nuclear power plant, the design documents of the nuclear power plant and the analysis documents of the power loss.

With model above, it is possible to simulate loss power source or switchboard incident.

As shown in Fig. 4, it's the diagnosis and warning on the influence of loss of power failure to nuclear safety. Through the above model, loss of power failure of NPP can be simulated.

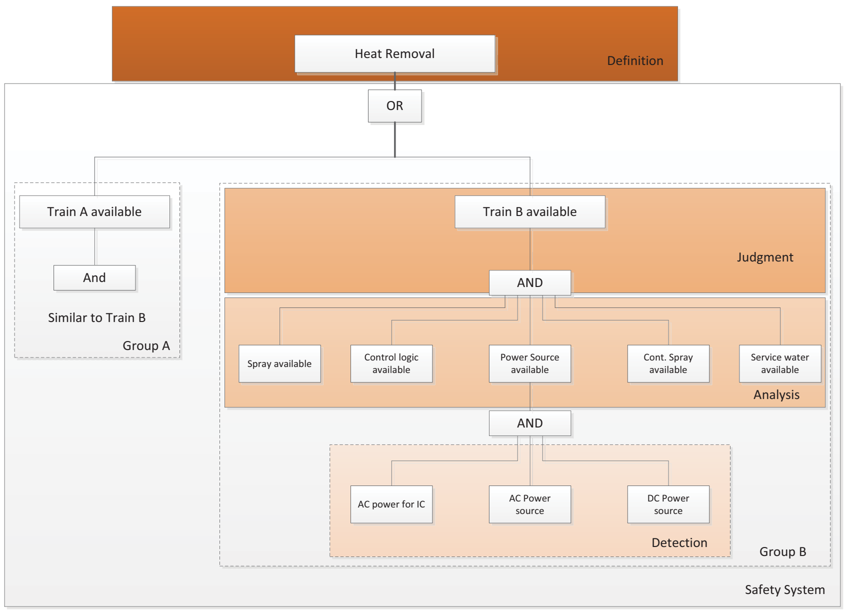

Fig. 4 Diagnosis and warning on the influence of loss of power failure to nuclear safety

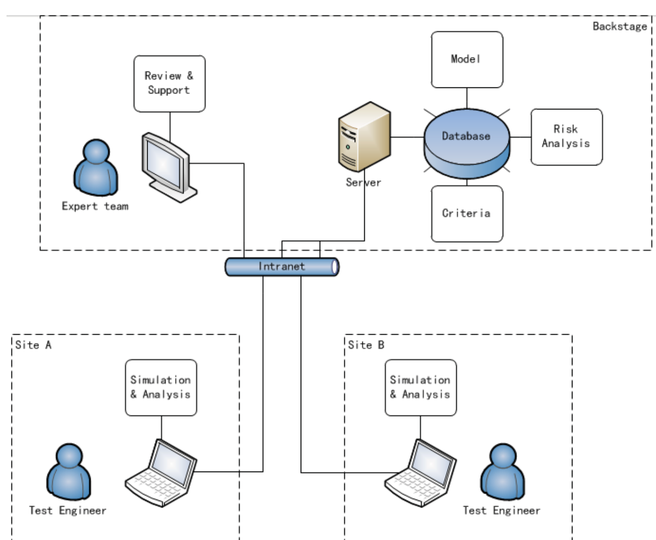

Fig 5 Real time simulation system of NPP power loss accident

The real time simulation system of NPP power loss accident is shown as Fig. 5. It's main functions are as follows:

--First, The electrical systems initial state input page can be provided, and the system initial state can be imported into the page according to the real-time data of the unit. And the manual input is provided as backup. The temporary changes involved can all be recorded through dialog box no matter automatically or manually. The test plan input page can be provided, and the existing test can be imported in.

--Second, taking the unit initial status and test plan as the input, the power supply changeover and influence of power loss failure can be real-time calculated through the model, including the steady-state results and transient processes, as shown in Figure 6.

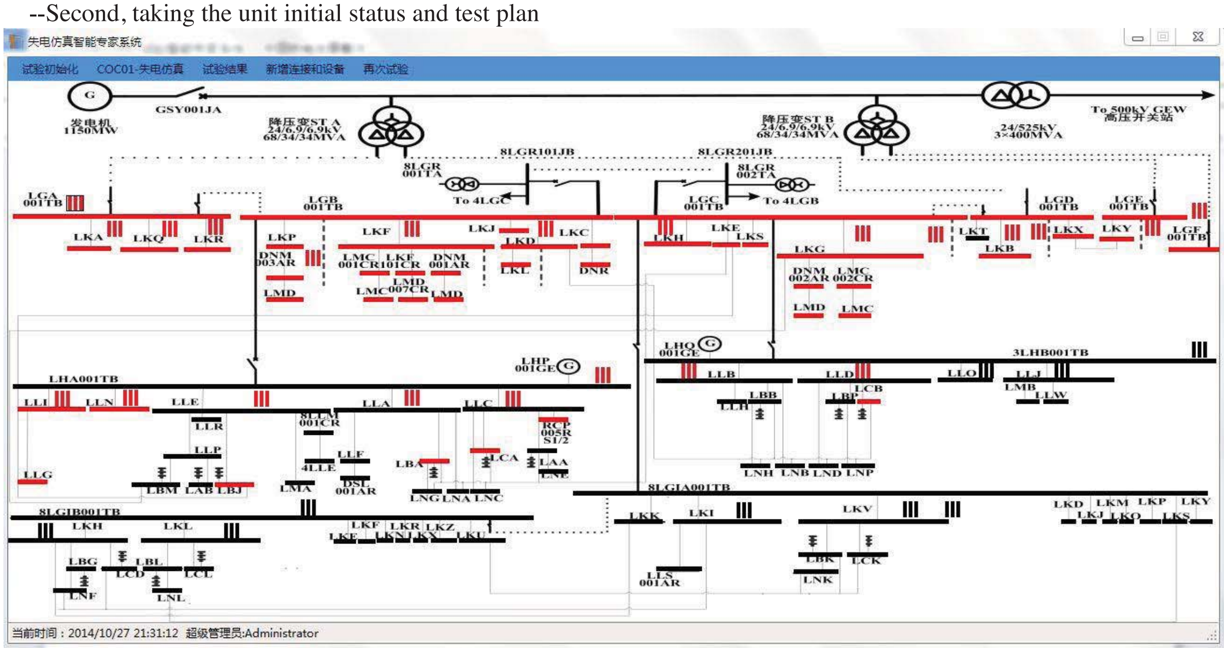

Fig. 6 Simulation over the influence of power loss failure

--Third, according to influence of power loss failure, signal failure criterion is analyzed.

--Fourth, through the mature thermal hydraulic program, the influence of power switch and power loss on unit parameters is calculated, and the availability of nuclear safety function is analyzed.

--Fifth, the simulation prediction results can be shown through graphics and trends, and the unavailable state of the equipment and the system, the safety state of the power station can be displayed directly through the overall picture, as shown in Figure 7.

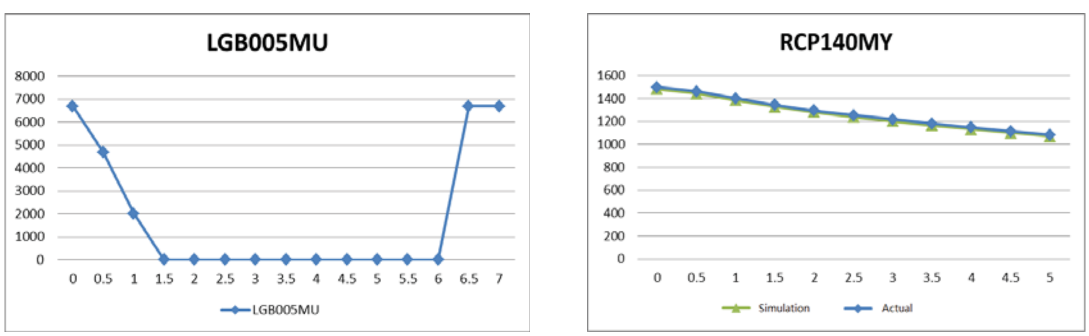

Fig.7 Simulation on RCP rotation speed after power loss failure

--Sixth, the accidents and defects can be predicted through parameters diagnosis, and a solutions can be deduced out , as shown in Figure 8.

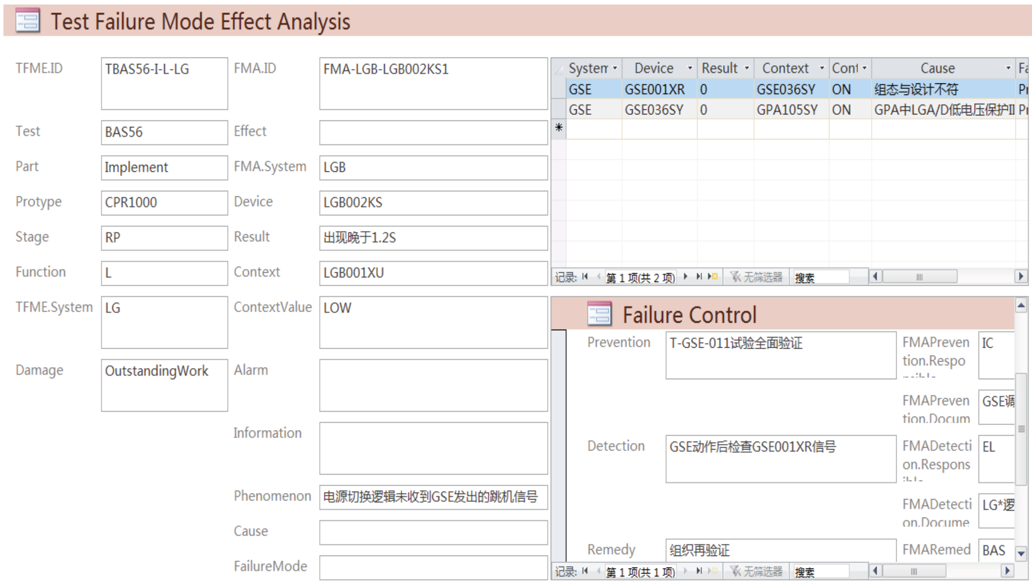

Fig. 8 Diagnosis of power loss failure and guidance

IV Conclusion

The NPP power system model presented is built from power system network to nuclear auxiliary system designed for safety function. Simulation result of loss of offsite power incident with this model shows the potential risk on nuclear safety and provides input for analysis during unit commission and maintenance, which is frequently required by both engineering and operation.

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