Research and Improvement of TG Equipment Load Shedding Control Scheme in Nuclear Power Plant

Le-Yuan Bai, Xu-Feng Wang, Gang Yin and Bin Zeng

Abstract Once the emergency diesel generator in operation in CPR1000 nuclear power plant (NPP), the selected equipment reloads in the pre-specified sequence after load shedding, and the important equipment should reload preferentially and successfully. This paper finds that the load shedding command for turbine and generator (TG) equipment is from non-classified turbine control system (NC-TCS) to motor control center (MCC) in a CPR1000 NPP. There is a risk that the more important equipment might fail to reload if TG equipment load shedding fails in case TCS system out of order. This paper adds a new TG load shedding path from class 1E distributed control system (1E-DCS) to MCC, and realizes the hard priority logic of TG load shedding by MCC control loop, increasing the reliability of TG load shedding command and eliminating the influence on other more important equipment. The improvement scheme proposed in this paper enhances the safety of NPP and cuts the cost of nuclear power engineering.

Keywords TG · Emergency diesel generator · Load shedding · Control · Improvement

1 Introduction

To improve the reliability of power supply to key equipment is an important means to ensure the safety of NPP. Normally the power of equipment is supplied by 500 kV offsite power via main transformer and step-down transformer in CPR1000 NPP. When 500 kV off-site power lost, 200 kV off-site auxiliary power will be put into operation via auxiliary transformer. The emergency diesel generator finally takes charge of power supply if 500 and 200 kV off-site power both lost, to ensure the automatic response of related systems, prevent damage of important equipment and ensure the safe shutdown of nuclear power unit [3] (Fig. 1).

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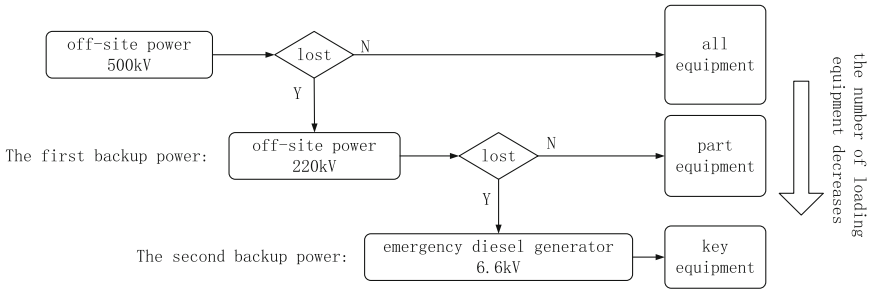

Fig. 1 The power supply of CPR1000 NPP

Table 1 The equipment and time of TG load shedding

No.	Equipment	Quantity	Load shedding time (s)
1	Turbine lube oil pump	1	25
2	Turbine jacking oil pump	2	25
3	Turbine lube oil vapor extractor	1	0
4	Generator seal oil pump	1	40
5	Generator vapor extractor	1	0

Once the power supply is switched to the emergency diesel generator unit, the grid breaker opens and the off-site power of plant is lost. Only certain important equipment starts to reload until the circuit breaker of the emergency diesel generator closes. To make sure of the success of reload, all the pre-selected key equipment has to shed load first and then reload in the pre-specified sequence. The sequence is established according to the importance of the equipment, and the more important the equipment is, the earlier the reload time is. The reload times start from 0 s and increase 5 s delay once. All equipment is forbidden to reload in advance [1, 4].

TG is the most significant equipment of conventional island in CPR1000 NPP. TG important equipment has to be powered by the emergency diesel generator when both 500 kV off-site power and 200 kV off-site auxiliary power fail, so that the turbine can be safely stopped in emergency and accidents can be avoided, such as bush burning, scored cylinder and so on.

2 Analysis of TG Load Shedding Scheme

2.1 TG Load Shedding Scheme

The TG of CPR1000 NPP 1 is a turbine-generator of million-kilowatt class, which is controlled by Siemens TCS platform. The following TG equipment should be powered by the emergency diesel generator, ensuring the turbine can be safely stopped in emergency (Table 1).

The reload process of TG equipment is as follows [2, 6]:

- The equipment will stop instantly as soon as the normal bus bar fails, but the operation feedback of the equipment will remain valid, according to line A.
- The emergency diesel generator prepares to start for no more than a time after the bus failure.
- When the emergency diesel generator is ready, normal load breaker will turn off, the operation feedback of the equipment will become invalid, and the load shedding command will be active, which time is 0, 25 or 40 s, according to line B.
- After the normal load breaker off, the load switch of the emergency diesel generator will be on and the voltage of 6.6 kV bus bar will be restored, shown as line C.
- Once the load shedding command disappears, the equipment will begin to reload, shown as line D (Fig. 2).

The load shedding of TG equipment is achieved by both 1E-DCS and NC-TCS in the control process shown as follows [7]:

- Normal start-stop control logics are completed in NC-TCS.
- Load shedding command are issued from 1E-DCS, and sent to NC-TCS by redundant hard-wire.
- The priority logic of load shedding over normal start-top is realized in NC-TCS.
- After priority, the final command is transmitted from NC-TCS to MCC by hard-wire, achieving start-stop in normal operation and load shedding in emergency (Fig. 3).

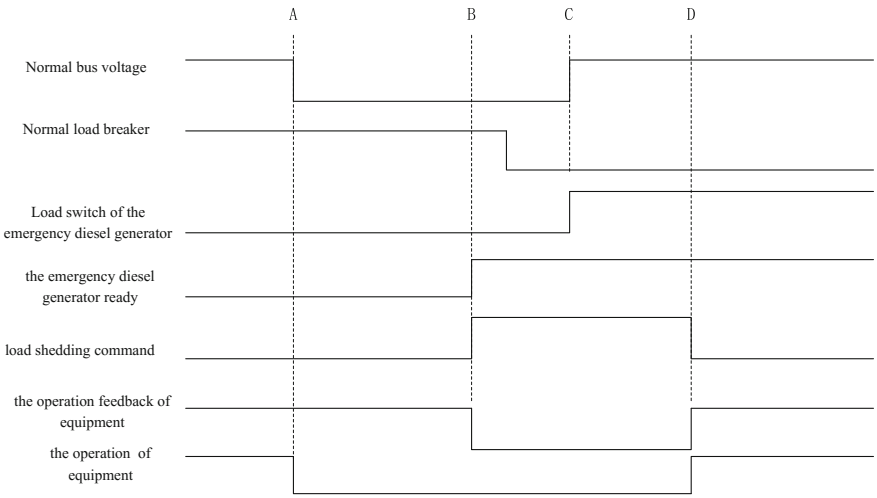

Fig. 2 The diagram of TG equipment load shedding sequence

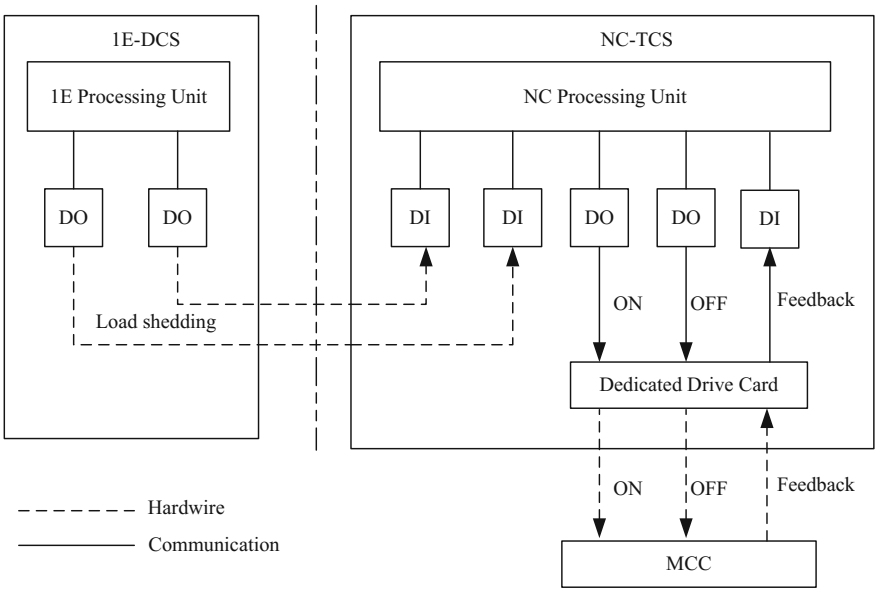

Fig. 3 The control scheme of TG equipment load shedding

The priority logic of load shedding over normal start-top is realized by the control module of sub-loop control (SLC) and DCM SWITCH in NC-TCS [5]:

- Under normal circumstances, the equipment switch module and sub-loop control module are in operation so that TG equipment can normally start up and be redundantly switched.
- When the load shedding signal is valid, the stop command comes out and the start-up command is reset, achieving the load shedding of TG equipment.
- When the load shedding signal disappears, the start-up command comes out and the fault signal of switching module is reset, achieving the reloading of TG equipment (Fig. 4).

2.2 Analysis of TG Load Shedding Scheme

The characteristics of TG equipment load shedding scheme are as follows:

- TG load shedding signals from 1E-DCS are two redundant hard-wired signals, which proves higher reliability.
- The priority logic of load shedding over normal start-top is realized by soft logic in NC-TCS.

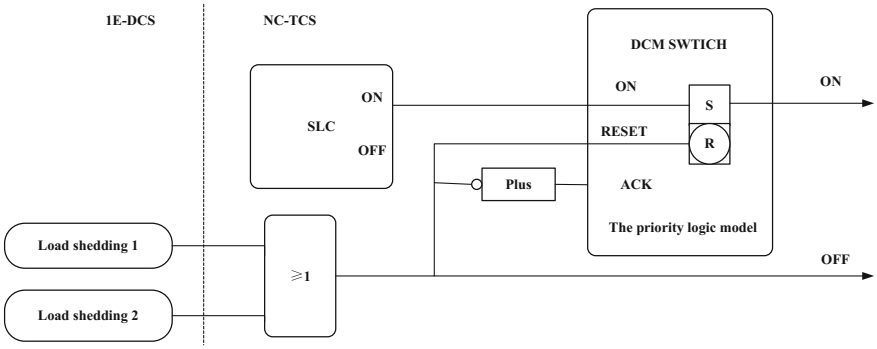

Fig. 4 The priority logic of TG equipment load shedding

Table 2 The characteristics of TG equipment load shedding control scheme

Characteristics		NPP 1
Load shedding command	Source	1E-DCS
	Redundancy	Redundant
Priority function	Platform	NC-TCS
	Implementation	Soft logic
Load shedding path	Implementation	1E-DCS → NC-TCS → MCC

- The load shedding path of TG is that: "1E-DCS sends the load shedding command → NC-TCS determines the priority → Motor Control Center starts or stops the equipment" (Table 2).

According to the analysis, the scheme of TG equipment load shedding has the following defects:

- The path of TG load shedding is not a whole 1E class path, which decreases the reliability of load shedding command. It is possible that the breakdown of the priority card or the platform in NC-TCS will result in the failure of TG load shedding command.
- The priority logic of load shedding over normal start-top is realized by not hardware in 1E-DCS, but soft logic in NC-TCS, which influences the success of TG load shedding. It is possible that the breakdown of the priority card or the platform in NC-TCS will result in the failure of TG load shedding.
- The safety function of the emergency diesel generator is affected. When it needs to start the emergency diesel generator because of loss of off-site power, if TG equipment load shedding fails, the load of the significant equipment in nuclear island may fail because the whole plant shared one diesel generator unit.

Taking into account the risk that the failure of TG equipment load shedding leads to the failure of nuclear island equipment loading, it is essential to improve TG load shedding scheme to enhance the reliability of TG load shedding.

3 Improvement of TG Load Shedding Scheme

According to the defects of the original TG load shedding scheme, the rational improvement scheme has been designed as follows:

- A new dedicated 1E class path is added for TG load shedding, which is from 1E-DCS to MCC directly by hard-wire, not through NC-TCS.
- A new priority function is realized by hard logic in the MCC control loop, not by soft logic in NC-TCS, so that the priority of new load shedding command is not influenced by NC-TCS, ensuring the success of TG load shedding.
- The logic design of TG load shedding in NC-TCS is reserved (Fig. 5).

Compared to the original scheme, the improvement scheme has the following advantages:

- TG load shedding has a dedicated 1E class path, which is not affected by the breakdown of the priority card or the platform in NC-TCS, enhancing the reliability of TG load shedding command.

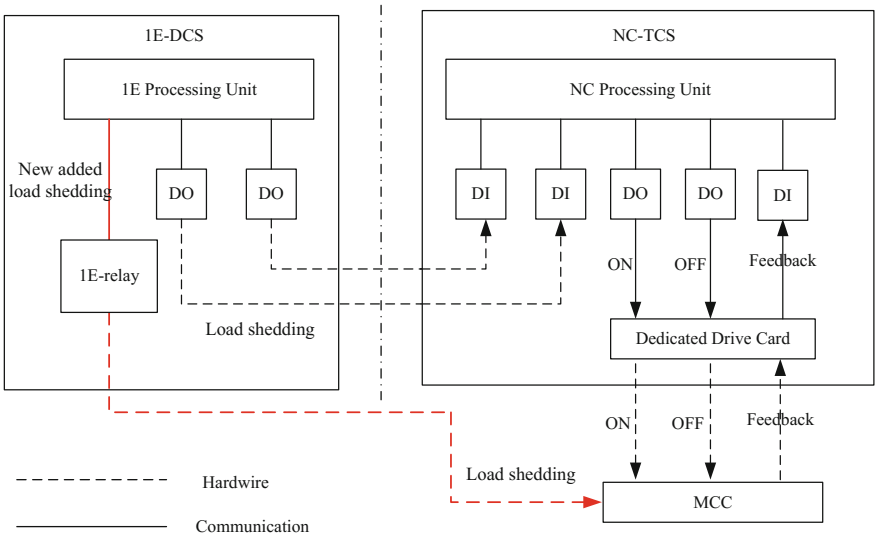

Fig. 5 The improvement scheme of TG equipment load shedding control

Table 3 Comparisons of TG equipment load shedding control schemes before and after the improvement

Characteristics		Before the improvement	After the improvement
Load shedding command	Source	1E-DCS	1E-DCS
	Redundancy	Redundant	Redundant
Priority function	Platform	NC-TCS	MCC + NC-TCS
	Implementation	Soft logic	Hard logic + Soft logic
Load shedding path	Implementation	1E-DCS → NC-TCS → MCC	1E-DCS → MCC 1E-DCS → NC-TCS → MCC

- TG load shedding has a hard priority logic in the MCC control loop, which is not affected by the breakdown of the priority card or the platform in NC-TCS, ensuring the success of TG load shedding.
- The safety function of the emergency diesel generator is not affected by the breakdown of NC-TCS, enhancing the safety of NPP.
- The logic design of TG load shedding in NC-TCS is reserved, avoiding changes of hardware interface and soft logic in 1E-DCS and NC-TCS, cutting the cost of nuclear power engineering (Table 3).

4 Conclusions

TG is the most important equipment in conventional island of NPP. On one hand, it's necessary to supply power to TG equipment when off-site power supply fails in emergency situations. On the other hand, the power supply to TG must not affect that to other more important equipment for the overall security of NPP. The scheme of TG equipment load shedding is researched in this paper, and the defect is found which might cause potential danger to the plant. The improvements were put forward to eliminate potential security risks and enhance the security. The improved scheme in this paper has been successfully applied in nuclear power projects and provides experiences for the following projects on TG equipment load shedding design.

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