The Evaluation of Battery Capacity Availability by Applying DC Load Shedding and Management for WH1000 NPP

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1. Introduction

Following Extended Loss of AC Power (ELAP) event, the station batteries are the only source of electrical power. The station batteries supply the DC busses and the AC vital instrument busses. Since AC emergency power is not available to charge the station batteries, battery power supply must be conserved to permit monitoring and control of the plant until AC power can be restored.

The purpose of this paper is to prolong essential equipment and control DC power supply by shedding and management DC loads from the DC busses as soon as practical. To meet this requirement, the effect of load shedding of equipment loads from the DC busses and of instrumentation from the AC vital busses have been reviewed. In addition to identify loads that need to be stripped from the plant DC buses, the operation strategy of the station batteries is developed. Also the results of plant specific evaluation are presented.

2. System Description

There are four independent class 1E 125V DC subsystems A, B, C and D respectively. Each consists of one 125V battery, one battery charger and one DC control center.

Subsystems A and B each use lead calcium type with 60 cells and 2415 ampere-hours (at an 8-hour rate) under 125V. Subsystems C and D each use lead calcium type with 60 cells and 825 ampere-hours (at an 8-hour rate) under 125V [1].

3. Load Requirements and Profile

The class 1E batteries designed to have sufficient capacity to supply 125V DC power to the class 1E DC loads and for control and switching of the class 1E system for 2.2 hours without battery charger support [1].

3.1 Subsystem A and B Load Profile

The DC subsystems A and B provide control power for AC load groups A and B respectively. These subsystems also provide DC power to the inverters for channels A and B respectively. Power for solenoid valves and diesel generator field flashing is also supplied by DC subsystems A and B [2].

3.2 Subsystem C and D Load Profile

The DC subsystems C and D provide DC power to the inverters for channels C and D respectively, as well as to the inverters for the two redundant residual heat removal isolation valves. Subsystem C also provides DC power to the turbine driven auxiliary feedwater pump controls [2].

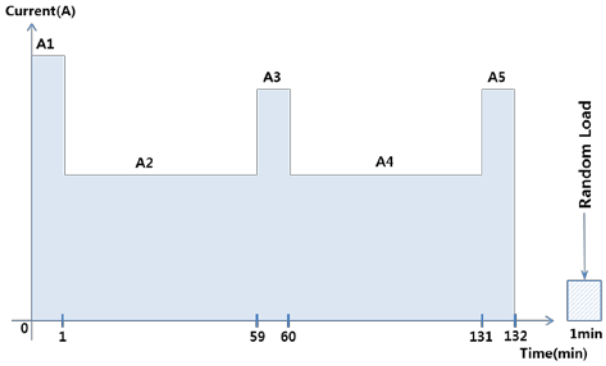

Fig. 1. Diagram of DC subsystem A and B battery load profile is derived from the load currents which are excited due to a station black out (SBO) with respect to design criteria.

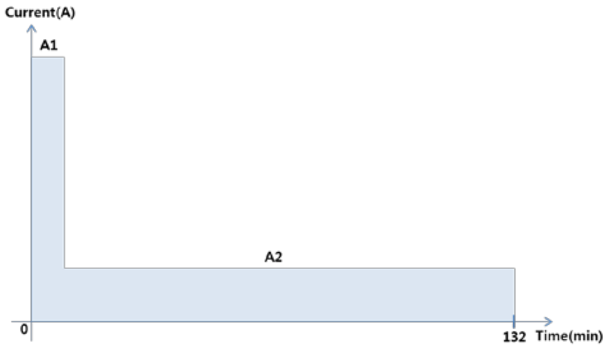

Fig. 2. Diagram of DC subsystem C and D battery load profile is derived from the load currents which are excited due to a station black out (SBO) with respect to design criteria.

4. The Review of Load Shedding

To conserve DC power supply by shedding non-essential DC loads from the DC busses as soon as practical. The intent of load shedding is to remove all large non-essential loads, consistent with preventing damage to plant equipment. Consideration should be given to the priority of shedding additional loads in case AC power cannot be restored within the projected life of the station batteries. To identify loads that need to be stripped from the plant DC buses, load shedding possibility reviewed detail load characteristics.

4.1 Review Result of Subsystem A and B Load

Three cycles of class 1E 4.16kV bus load shedding and diesel generator load sequencing with circuit breaker operation shall be postulated. The emergency diesel generator starting system which is essential load will be utilized at T=0, 59 and 131 minutes of the battery load profile for a period of 1 minute.

The pressurizer power operated relief valves (solenoid actuated) provide a safety related means for reactor coolant depressurization to achieve cold shutdown. As a result, energization of actuators is difficult to determine during the load profile which will be considered as a random load.

The function of reactor trip switchgear is to interrupt the power to the control rod drive mechanism which will reactor shutdown immediately after loss of voltage on class 1E 4.16kV bus.

Plant protection system and isolation relay panels are installed continuously energized and the max current conservatively considered for essential load.

The 7.5kVA inverter which supplies vital instrumentation power and nuclear steam supply system (NSSS) protection cabinet is possible to switch the other subsystem inverter. It is assumed that 2 of 4 channel instrument will sufficiently monitoring plant state. The entire list of vital instruments is included in reactor coolant system (RCS) hot leg temperature, RCS cold leg temperature, RCS pressure, SG level, core exit thermocouple (CET) temperature, RCS passive injection (SI accumulator) level, pressurizer level, reactor vessel level indicating system, containment pressure, auxiliary feed water flow, SG pressure, CST level, spent fuel pool level, battery capacity and DC bus voltage, neutron flux, containment temperature.

The 25kVA inverter supplies 120V-AC power to nuclear instrumentation system, logic cabinets and equipment associated with engineered safety features. This load is also switching the other subsystem inverter.

After reactor coolant pump trip, indication power of switchgear which is continuously supplied could be shedding.

The 4.16kV switchgear breaker control loads are based on the tripping and closing of associated circuit breaker, in accordance with three cycle of bus load shedding and sequencing. Following ELAP event, class 1E 4.16kV loads such as charging pump, nuclear service circulating water pump, component cooling water pump, residual heat removal (RHR) pump, essential chiller compressor, containment spray pump, auxiliary feed water pump are assumed to be stopping at the time of bus load shedding. After actuated the trip coil, load sequencing on the diesel generator takes place by sequentially reclosing circuit breakers at predetermined intervals. Under all active equipment are not operating and breakers are already ready to closing, reclosure load of the subject breakers which is initiated by energization of the closing coil followed immediately by spring charging operation could be shedding from battery.

The 480V load center breaker control loads are based on the tripping and closing of associated circuit breaker, in accordance with three cycle of bus load shedding and sequencing. Reclosure load of 480V load center breaker also could be shedding from battery.

Table I: Review Result of Shedding Possibility for Subsystem A and B

Load Description	Shedding Possibility
Emergency diesel generator starting system	essential
Pressurizer power-operated relief valves	essential
Reactor trip switchgear	essential
Plant protection system	essential
Isolation relay panels	essential
7.5 kVA Inverter	switching
25 kVA Inverter	switching
Reactor coolant pump trip switchgear	shedding
4.16 kV switchgear	shedding
480V load center	shedding

4.2 Review Result of Subsystem C and D Load

The emergency feedwater steam driven turbine's valve and speed controls actuator is continuously supplied from the class 1E 125V DC subsystem C. This load is the only safety function of heat removal from RCS.

The 7.5kVA inverter which supplies vital instrumentation power and NSSS protection cabinet is possible to switch the other subsystem inverter.

Table I: Review Result of Shedding Possibility for Subsystem C and D

Load Description	Shedding Possibility
Emergency feedwater turbine controls	essential
Isolation relay panels	essential
7.5 kVA Inverter	switching
Reactor coolant pump trip switchgear	shedding
25 kVA Inverter	shedding

The primary application of the 25 kVA inverter is to power the RHR inlet suction valve actuators located within the containment area. These valves are normally closed and opened only for RHR system operation. After RCS pressure is reduced to 30kg/cm^2 and RCS temperature is reduced to approximately 177 ℃. These limits are not usually met during battery duty cycle after reactor shutdown. As a result, 25 kVA inverter load could be shedding until RHR system operating.

5. The Operation Strategy

Emergency operating procedures (EOP) for Westinghouse type plant already identified load shedding lists that need to be stripped at ELAP [3]. But there is no guidance to when the DC loads should be shed and how to manage switching DC loads. In this session the operation strategy of the station batteries is developed. Also this strategy needs to satisfy that plants should monitor vital instruments for plant recovery from ELAP and continuously supply the DC load of essential equipment. After SBO the load will shed by dispatched local operator in 30 minutes during 10 minutes following Korean regulatory requirement [4].

3.1 The Operation Strategy of Subsystem A

The 4.16kV switchgear breaker and the 480V load center breaker control loads must be de-energized at 40 minutes after loss of all AC power.

The 7.5kVA inverter of DC subsystem A will supply vital instruments power in 131 minutes until depleted. Since then, the function of this inverter is switching to the 7.5kVA inverter of DC subsystem D.

The 25kVA inverter of DC subsystem A will supply 120V-AC power to nuclear instrumentation system, logic cabinets and so on in 300 minutes until depleted. Since then, the function of this inverter is switching to the 25kVA inverter of DC subsystem B.

Three cycles of the emergency diesel generator starting power is essential load (A1, A4, A6)

The pressurizer power operated relief valves load is considered as a random load.

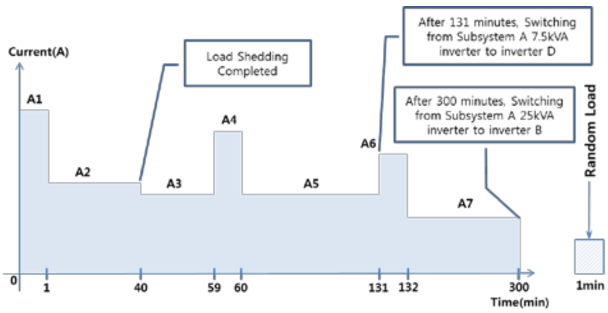

Fig. 3. Battery load profile of DC subsystem A is applied load shedding and management strategy.

3.2 The Operation Strategy of Subsystem B

The 4.16kV switchgear breaker and the 480V load center breaker control loads must be de-energized at 40 minutes after loss of all AC power.

The 7.5kVA inverter of DC subsystem B will supply vital instruments power in 150 minutes until depleted. Since then, the function of this inverter is switching to the 7.5kVA inverter of DC subsystem C.

The 25kVA inverter of DC subsystem B will be de-energized for 40 to 300 minutes after loss of all AC power. Because subsystem A will supply 120V-AC power to nuclear instrumentation system in 300 minutes until depleted. Since then, the 25kVA inverter of DC subsystem B will be energized for 300 to 480 minutes after depletion of subsystem A.

Three cycles of the emergency diesel generator starting power is essential load (A1, A4, A6)

The pressurizer power operated relief valves load is considered as a random load.

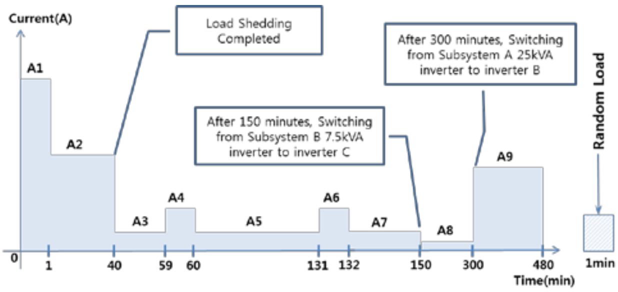

Fig. 4. Battery load profile of DC subsystem B is applied load shedding and management strategy.

3.3 The Operation Strategy of Subsystem C

The 25 kVA inverter which is to power the RHR inlet suction valve actuators must be de-energized at 40 minutes after loss of all AC power.

The 7.5kVA inverter of DC subsystem C will be de-energized for 40 to 150 minutes after loss of all AC power. Because subsystem B will supply 120V-AC power to vital instruments in 150 minutes until depleted. Since then, the 7.5kVA inverter of DC subsystem C will be energized for 150 to 480 minutes after depletion of subsystem B inverter.

The emergency feedwater turbine's valve and speed controls actuator is continuously supplied from the subsystem C during 480 minutes.

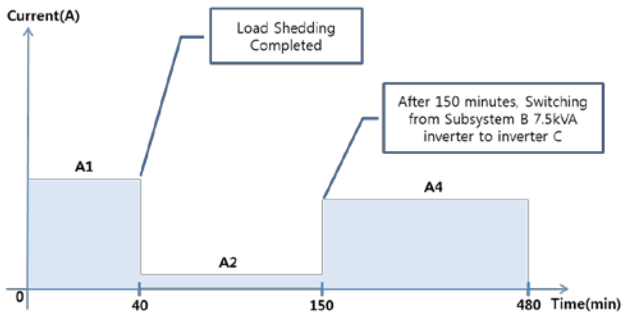

Fig. 5. Battery load profile of DC subsystem C is applied load shedding and management strategy.

3.4 The Operation Strategy of Subsystem D

The 25 kVA inverter which is to power the RHR inlet suction valve actuators must be de-energized at 40 minutes after loss of all AC power.

The 7.5kVA inverter of DC subsystem D will be de-energized for 40 to 131 minutes after loss of all AC power. Because subsystem A will supply 120V-AC power to vital instruments in 131 minutes until depleted. Since then, the 7.5kVA inverter of DC subsystem D will be energized for 131 to 480 minutes after depletion of subsystem B inverter.

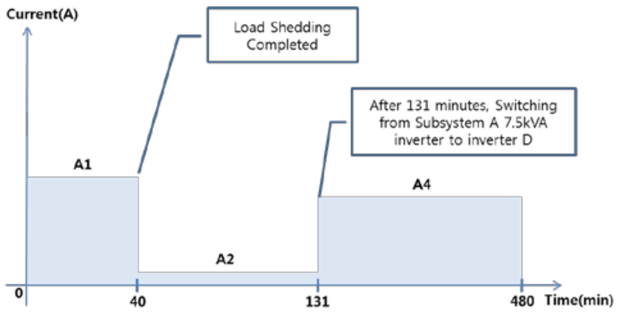

Fig. 6. Battery load profile of DC subsystem D is applied load shedding and management strategy.

6. Evaluation Results

In this section the results of plant specific evaluation are presented applying DC load shedding and management. The method used for evaluation the class 1E batteries is based on KEPIC EEG 1200 recommended practice for sizing lead-acid batteries for stationary applications [5, 6].

The results of evaluation show that the class 1E batteries have sufficient capacity to supply 125V DC power to the class 1E DC loads and maintain vital instrumentation for 8 hours without battery charger support. There are several basic factors which are temperature correction factor, aging factor and design margin takes into account.

This result means that early load shedding and management can significantly extend the availability of the plant's Class 1E batteries.

7. Conclusions

The proposed operation strategy provides actions to establish DC loads and time at which they should be shed and switch.

The plant specific availability of the class 1E batteries evaluated considering load shedding of equipment loads from the dc busses and instrumentation from the ac vital busses. DC power of WH1000 nuclear power plant is verified in an ELAP sufficient capacity to supply power to essential equipment loads and maintain vital instrumentation for 8 hours.

In addition to review load shedding possibility of detail load characteristics, every plant has to be prepared specific procedure according to the shedding and switching strategy of DC loads in order to conserve and prolong the station battery power supply.

This result of evaluation also supports plant response to near-term actions to address the effects of an ELAP in response to the Fukushima Daiichi Event and Stress Test.

REFERENCES

[1] Korea Hydro & Nuclear Power CO., LTD. (KHNP), Final Safety Analysis Report (FSAR) for reference plant.

[2] KHNP, Class 1E 125V DC System Battery and Battery Charger Sizing, Calculation Sheet, 1986.

[3] KHNP, Emergency Operating Procedures (EOP) ECA-0.0 Loss of all AC power.

[4] Korea Institute of Nuclear Safety (KINS), Korean Regulation Guide 9.19 Extended loss of All AC power, KINS/RG-N09.19, 2016.

[5] Korea Electric Association (KEA), Korea Electric Power Industry Code (KEPIC) EEG Station Battery EEG 1200 Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications, 2015 Edition.

[6] Nuclear Logistics INC. (NLI), Specifications of Nuclear class 1E flooded batteries.