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Transient Analyses of SBO and ELAP Events for CANDU6 NPP

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1. Introduction

SBO (Station Blackout) refers to the complete loss of alternating current electric power to the essential and nonessential switchgear buses in a nuclear power plant. Station blackout therefore involves the loss of offsite power concurrent with turbine trip and failure of the onsite emergency ac power system, but not the loss of available ac power to buses fed by station batteries through inverters or the loss of power from alternate ac sources [1].

On the other hand, Extended Loss of All AC Power (ELAP) event is defined as a loss of all off-site and on-site AC power sources for a potentially indefinite time period, which will challenge the long-term cooling of the reactor core [2].

There are many similarities and some differences between SBO and ELAP events. The thermal-hydraulic transient analysis using CATHENA code was performed to provide insights for SBO and ELAP in Wolsong Unit 2. It will be helpful for developing AMP (Accident Management Program) to cope with SBO and ELAP for CANDU6 NPP.

2. Nodalization Model

Wolsong Unit 2 was selected as a representative plant for CANDU6 NPP. The nodalization model is shown in Fig. 1. 380 fuel channels are separated to 4 paths, which are divided into 7 groups based on the channel power and flow. Some models such as degasser condenser tank, steam generator gravity feed from dousing tank, RCP seal leakage and MSSV manual open were added.

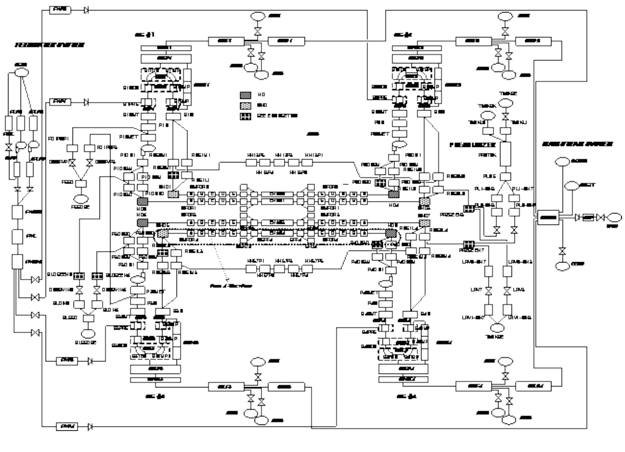

Fig. 1. Wolsong Unit 2 CATHENA Nodalization Model

3. Initial Conditions and Assumptions

3.1 Initial Conditions

Initial conditions calculated for 100% FP operation are well agreed with design values as shown in Table 1.

Table 1: Initial Conditions for 100% FP operation

Parameter	Design Value	Calculated Results			
		Path 1	Path 2	Path 3	Path 4
RIH Pressure (MPa(a))	11.35	11.27	11.27	11.27	11.27
RIH Temperature (℃)	266	268.2	268.3	268.3	268.3
ROH Pressure (MPa(a))	9.99	10.03	10.03	10.04	10.04
ROH Quality (%)		3.89	3.88	3.81	3.85
Core Flow (kg/s)	1925	1928	1929	1930	1928
Heat Load to SG (MW)	2064	516	517	516	515
PZR Level (m)	12.48	12.48			
SG Pressure (MPa(a))	4.70	4.69	4.69	4.69	4.69
SG Steam Flow (kg/s)	1033	258	258	258	258
Feedwater Flow (kg/s)	1034	258	260	257	257
SG Level	2.5	2.54	2.54	2.54	2.55
Feedwater Temperature (℃)	187	187	187	187	187

3.2 Assumptions

In ELAP definition, power directly or indirectly from batteries is assumed available. But ELAP will be caused by the extreme natural disaster such as earthquake and tsunami. So in this study, ELAP is assumed to be caused by the earthquake having 10,000 year frequency cycle with greater power than design basis earthquake of Wolsong Unit 2.

Class I power is uninterruptible DC power normally derived from the Class III (AC power interruptible for short periods) system via a rectifier connected with a battery. The battery will supply the DC load for a specified period following a failure of Class III power or of the rectifier. Class II is uninterruptible AC power produced by an inverter supplied with DC from a Class

I system. None of the Class I and II systems are seismically qualified. So there are no available fixed powers for ELAP. Loop isolation valves are fail-lock type and therefore remain open. Consequently loop isolation is not available for ELAP. The availability of various powers for ELAP and SBO is shown in Table 2.

RCP seal leakage is simulated with valve model having the area corresponding to the leak flow of 25 gpm at the 100% FP condition.

Liquid relief valves are assumed to be fail-opened due to the failure of instrument air. So the coolant are discharged to the degasser condenser tank but not discharged to reactor building by virtue of degasser condenser relief valve. The availability of various components and system for ELAP and SBO is shown in Table 2.

Main steam safety valves for SG over-pressurization protection are available for both SBO and ELAP. But MSSV open time for SG depressurization is different. MSSVs are assumed to be opened at 30 minutes for SBO, because MSSV can be opened in main control room. But for ELAP, MSSV can be opened only in secondary control room or MSSV room junction box with mobile battery set. So MSSVs are assumed to be opened at 60 minutes for ELAP, and gagging is required to keep the MSSV open.

If SG pressure are reduced below 345 kPa(g) by MSSV open, makeup isolation valves(3461-PV7, -PV41) are opened automatically and gravity injection from the dousing tank to SG is initiated. Makeup isolation valves are fail-open type and opened initially for ELAP.

For ELAP, HP (high pressure) ECC (emergency core cooling) water tank cannot be automatically operated, because there is no power to open ECC isolations valves. So 400 kW medium-sized generator is required to open the ECCS isolation valves. HP ECC water tank injection is assumed to be initiated at 140 minutes by operator action.

Table 2: Availability of Power, Component and Systems in SBO and ELAP Events

	SBO	ELAP
Uninterruptible DC Power (Class I)	O	X
Uninterruptible AC Power (Class II)	O	X
Standby Diesel Generator (Class III)	X	X
Off-site Power (Class IV)	X	X
Battery	O	X
Emergency Power Supply	O	X
PZR steam bleed valve	X	X
Condenser Steam Discharge Valve	X	X
Liquid Relief Valve	X	X
Main Steam Safety Valve	O	O
Degasser Condenser Relief Valve	O	O
Loop Isolation	O	X
Instrument Air	X	X

O : available / X : not available

4. Calculation Results

Table 3: Event Sequences for SBO and ELAP

Event	Time [sec]	
	SBO	ELAP
• Loss of Class IV power • RCP stop • Feedwater pump stop • PZR heater stop • Turbine stop • Feed and Bleed system stop • PZR steam bleed valve stop • LRV fail-open • RCP seal leak	0.0	0.0
• Reactor trip	7.835	0.0
• EPS activation	1,800	-
• MSSV manual open	1,800	3,600
• LOCA signal by low HTS pressure	1,906	-
• Loop isolation	1,906	-
• Gravity feed from dousing tank to SG	2,270	3,804
• ECC conditional signal by sustained low HTS pressure	2,506	-
• HP ECC injection	2,506	8,400
• Calculation end	86,400	86,400

Table 3 shows the event sequences for SBO and ELAP.

The reactor trips at 0 sec for ELAP, because SDS1 is dropped promptly due to the loss of DC power and battery. But for SBO, the reactor trips at 7.825 sec by SDS1 and SDS2 trip logic (Fig. 2).

The SG pressure begins to decrease after MSSVs are opened. SG pressure behaviors are dependent on the MSSV open time as shown in Fig. 3.

Reactor header pressure begins to decrease after reactor trips. That begins to decrease drastically after MSSV open. And the latter pressure increase is due to injection from HP ECC water tank. For SBO, HP ECC injection is initiated automatically by both LOCA signal (reactor header pressures decrease below 5.25 MPa) and ECC conditional signal (ROH pressure lasts for 10 minutes below 5.25 MPa). But for ELAP, operator should use 400 kW medium-sized generator to open the ECC isolation valves. Fig. 4 shows that reactor header pressure behaviors are corresponds to MSSV open and HP ECC injection.

Fig. 5 shows SG gravity feed from dousing tank to SG. It is assumed that the maximum flow of 34 kg/sec (8.5 kg/sec per SG) is injected at early stage and adjusted to the decay heat after the initial inventory is recovered.

Fig. 6 shows SG inventory. If MSSV is opened, then the SG inventory is exhausted rapidly regardless of

MSSV open time. It is because that the SG feedwater is evaporated as SG pressure decreases below the saturation pressure of SG feedwater temperature.

Fig. 7 shows reactor header temperature. Reactor header temperature begins to decrease drastically after MSSV open. The main heat removal mechanism is SG heat transfer and the HP ECC injection to makeup the RCP seal leakage is auxiliary. The ROH temperature is maintained among 100℃ ~110℃.

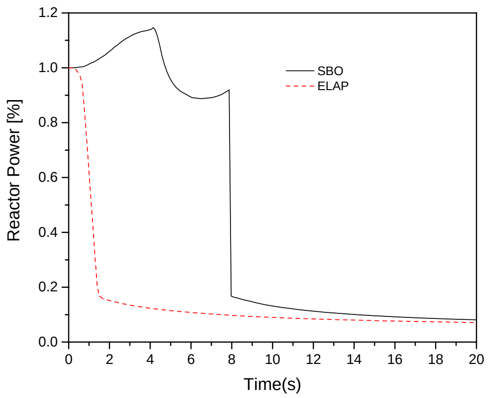

Fig. 2. Reactor Power

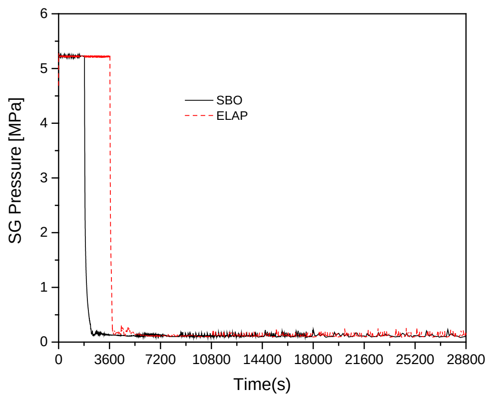

Fig. 3. SG Pressure

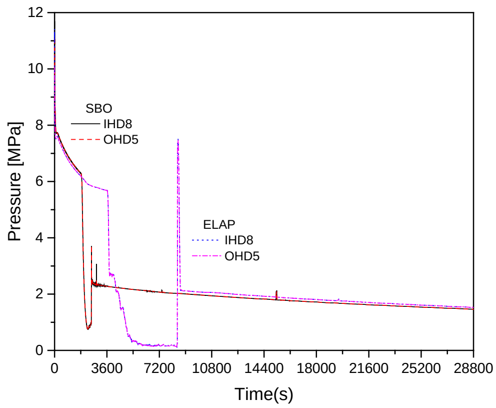

Fig. 4. RIH and ROH Pressure

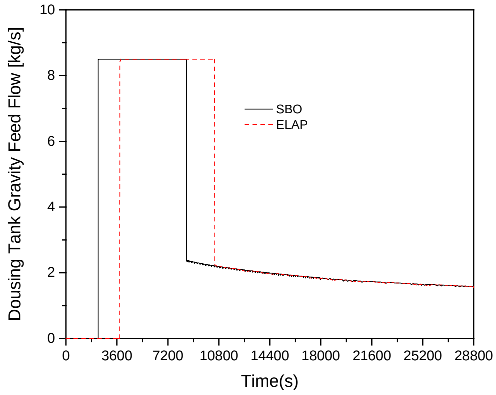

Fig. 5. Gravity Feed from Dousing Tank to SG

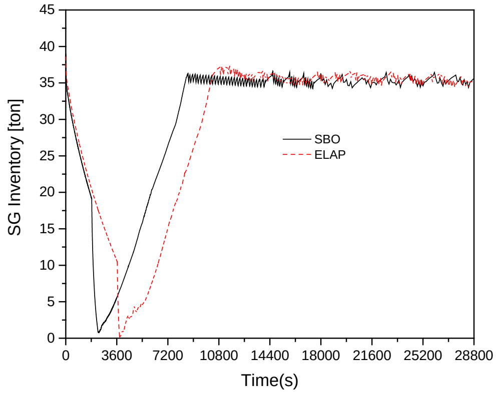

Fig. 6. SG Inventory

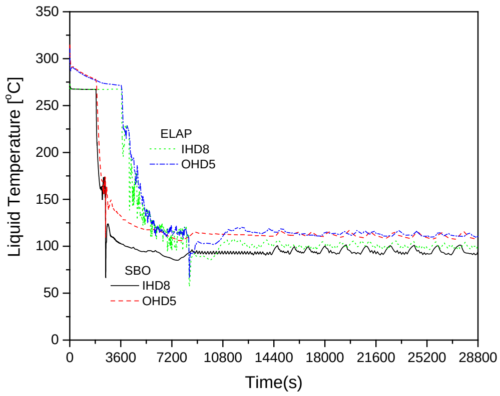

Fig. 7. RIH and ROH Temperature

5. Conclusion

The thermal-hydraulic transient analysis was performed to provide insights for SBO and ELAP events. There are some differences such as the available power, MSSV open time, HP ECC injection time between SBO and ELAP. ELAP needs mobile battery set and 400 kW medium-sized generator to open MSSV and HP ECC isolation valves. Nevertheless the whole transient behaviors are very similar with each other.

This calculation results can be directly applied to the development of EOP (Emergency Operating Procedures) and MOG (MACST (Multi-barrier Accident Coping Strategy) Operating Guidelines) for CANDU6 NPP.

REFERENCES

[1] US NRC Regulatory Guide 1.155, Station Blackout, August 1988
[2] Westinghouse, Reactor Coolant System Response to the Extended Loss of AC Power Event for Westinghouse, Combustion Engineering and Babcock & Wilcox NSSS Designs, WCAP-17601-P Revision 0, August 2012.