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Qualitative Evaluation of FLEX Strategies in Response to APR1400 Extended SBO for Risk-Informed Decision Making

Park Jong-hoon [a*], Park Joo-il [a], Ryu Hyo-sun [a], Jonathan Amfoh Blankson [a], Lim Hak-kyu [a]
[a] *KEPCO International Nuclear Graduate School, Ulsan, Republic of Korea*
[*] *Corresponding author: narcissus8787@nate.com*

1. Introduction

One of the representative accidents correlated to the electric power is Station Blackout (SBO), which indicates loss of offsite power (LOOP) parallel with turbine trip and unavailability of the onsite emergency diesel generator (EDG) [1]. Upon initiation of SBO, particularly alternate ac (AAC) sources and station batteries are available and the failure to start AAC DG usually termed as extended SBO. The extended SBO is acknowledged to be among the principal contributors to core damage frequency (CDF) in accordance with the State-of-the-Art Reactor Consequence Analyses (SOARCA) report [2]. The events at the Fukushima Daiichi nuclear power plant in 2011 showed that the loss of electrical power (LOOP) followed by station blackout event (SBO) and loss of the ultimate heat sink (LUHS) can have large impact on the safety of the nuclear power plant (NPP). Since that accident, nuclear industries developed onsite and offsite equipment concept that provides an additional layer of defense in depth, called diverse and flexible mitigation strategies (FLEX) [3].

This paper is a continuation of the previous work entitled "HEPs Calculation for FLEX Strategies in Response to APR1400 Extended SBO for Risk-Informed Decision Making" [5]. In the previous work, there were deficient data and procedures of FLEX that affected the human error probabilities (HEPs) calculation. The need therefore to refine. In this paper, we have done qualitative evaluation of a mobile GTG (3.2 MW) using the actual procedures used in the Korea Hydro & Nuclear Power (KHNP) [4, 5, 7].

2. Development of Accident Sequences for APR1400 Extended SBO

This section describes accident sequence development using a mobile GTG to cope with an APR1400 extended SBO scenario which is graphically modeled in event tree. In the APR1400, extended SBO involves complete loss of AC electric power to the Class 1E and non-Class 1E switchgear buses as well as the failure of a non-Class 1E AAC DG [6]. Under the extended SBO condition, the only DC battery is available for the turbine driven auxiliary feedwater pump (TDAFWP) which supply cooling water to the steam generator (SG). The capacity of DC battery is 8 hours and within this period plant safety needs to be recovered. Henceforth, a mobile GTG (3.2 MW) could be connected to one division of the 4.16 kV class 1E buses and the purpose is to recover AC power to maintain the secondary heat removal, feed and bleed operation and containment heat removal [6].

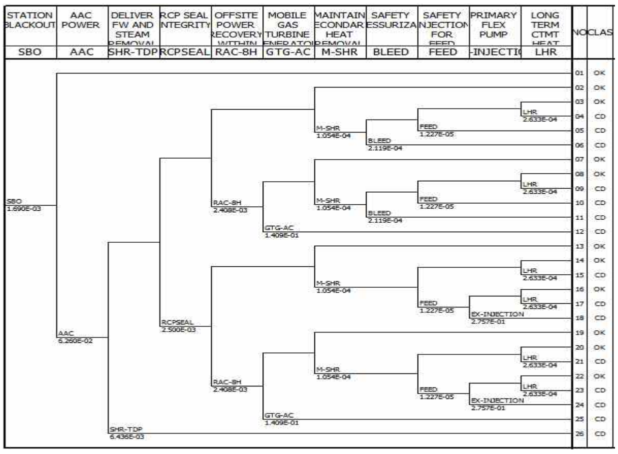

Fig. 1. Event Tree for an Extended SBO using Large GTG

3. Study for mobile GTG Procedures

Comparing with last year's procedure, some changes has been made to this year procedures. Actual procedure of mobile GTG being deployed along with extended SBO is considered at the plant [4, 7].

Procedure assumed a loss of off-site power situation by an external event and all EDGs and AACDG are unavailable. Reactor is tripped after loss of all AC power. Turbine-generator is also tripped by reactor trip. All rod is inserted after transient.

There are several procedures/steps to deploy and install the mobile GTG. Table 1 below outlines the main steps required and compare with previous work.

Table 1. Deployment procedures of mobile GTG

Steps	Procedures of previous study	Procedures of current study
Step 01	Diagnose the plant abnormal conditions and perform abnormal procedure guideline.	Diagnose the reactor trip symptoms and starts to perform emergency operating procedure.
Step 02	Verify reactor trip occurrence and perform post trip actions.	
Step 03	Check LOOP occurrence and perform emergency operating procedures	Check LOOP occurrence and operator try to operate EDGs but fail

Step 04	If the operator fails to activate EDG, then declare an SBO	Declare SBO condition and try to operate AACDG but fail
Step 05	Operator check AAC DG availability. If not available extended SBO is declared.	
Step 06	Operator load sheds dc bus to preserve battery for vital instrumentation & control	Operator load sheds dc bus to preserve battery for vital instrumentation & control
Step 07	STA may instruct the operator to deploy and install FLEX equipment.	
Step 08	FLEX equipment deployment route are reviewed.	
Step 09	Deployment of small GTG and large GTG in front of the auxiliary building.	Move mobile GTG to plant site
Step 10	Operator checks status of the circuit.	
Step 11	Connect powerline to 480V for small GTG.	(Not the scope of the study)
Step 12	Connect powerline to class 1E 4.16kV for large GTG.	Disconnect unused cable and set up cable of mobile GTG to safety bus
		Set oil supply line of mobile GTG
		Starts no-load operation of mobile GTG
Step 13	Perform pre-operational checking of large GTG.	
Step 14	Energize mobile small GTG.	(Not the scope of the study)
Step 15	Energize mobile large GTG.	Connect power to safety bus and restore power to individual load
Step 16	Check procedure if the vital bus is not restored	
Step 17	Deployment and staging of primary FLEX pump.	(Not the scope of the study)
Step 18	Connect primary FLEX pump to IRWST line	
Step 19	Connect primary FLEX pump hose line to SI injection line via DVI.	
Step 20	Perform pre-operational check for primary FLEX pump.	
Step 21	Start primary FLEX pump.	
Step 22	Check procedure if RCS inventory is not recovered.	Perform long-term safety operation for cold shutdown

4. Time Analysis for Extended SBO

Assessing the probability of human action failure includes accomplishing a timing analysis to identify how much time is available to complete an action compared to the time available to effectively complete the action. It is assumed that after 8 hours from the start of SBO, the mobile GTG is required. The structure of timing analysis for FLEX is shown below.

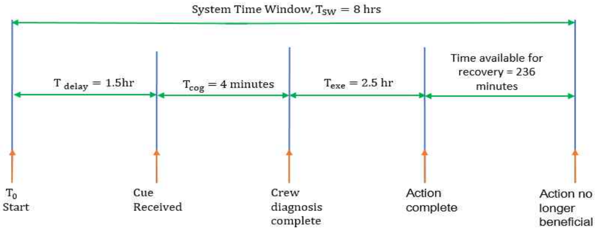

Fig. 2. Timing analysis for extended SBO

In timing window analysis, as long as this action is completed within about 8 hours from the start of the SBO, the steam generators will not overfill or boil dry.

Delay time T_{delay} = 90 minutes. This is the duration of time it takes to diagnose the situation and begin the deployment of mitigating strategies equipment, measured from the time of initiating event.

Cognition time, T_{cog} = 4 minutes include the time for operators to receive enough indication, evaluate the written instructions, and take any necessary preparatory actions to begin the deployment actions.

execution time, T_{exe} = 150 minutes which provide FLEX equipment deployment, staging, installation, the time for pre-operational check, and time to re-power the bus.

So, Time available for cognition and recovery minutes T_W = 244 mins. (About 4 hours) Also it has 236 mins of time margin. (About 4 hours).

According to the procedure of the NPPs, however, the mobile generator needs to succeed in energizing and connecting within at least of 2hrs, in case of extended SBO [7]. Therefore time margin is 6 hrs.

The 2 hours of load connection through the mobile generator causes high stress and work load to operators or staffs, hence the expected value in HEPs calculation is likely to increase. It is therefore required to re-evaluate HEP calculations in deploying, installing and energizing mobile GTG within 2hrs compared to previous years' work of 4 hrs.

5. Conclusion

Inaccurate human-action is a key contributor to the risk and reliability of several complex engineering systems. For instant, about 90% of nuclear industry accidents are occurred by inaccurate human actions [8, 9]. Human reliability analysis (HRA) was developed from the basic need to comprehend the human role in the operation of complex systems. Hence, a realistic evaluation of human error probabilities (HEPs), a foremost goal of HRA, can disclose weak links in a system which can be corrected before any serious disaster occurs.

Our Studies indicated that in a short time of expectation to deploy, install and energize FLEX equipment for continuous removal of secondary heat, as outlined in actual NPP procedures, HEP is expected to increase, hence the need to re-evaluate and improve on actual FLEX strategy procedures.

ACKNOWLEDGMENTS

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