Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 24-25, 2024

Analysis of the impact of MACST equipment on Seismic probabilistic safety assessment

Seunghyun Jang[a*], Min Kyu Kim[a]
[a]*Structural and Seismic Safety Research Division, Korea Atomic Energy Research Institute, 111, Daedeok-Daero 989 beon-gil, Yuseong-gu, Daejeon, Korea*
[*]*Corresponding author: jsh872@kaeri.re.kr*

Keywords : Seismic probabilistic safety assessment, ELAP, Portable equipment, MACST

1. Introduction

Since the Fukushima accident in March 2011, the issue of the safety of Korean nuclear power plants due to extreme natural disasters exceeding design basis has been raised. As the coping strategy of this issue in Korea, the safety of nuclear power plants has been improved against such disasters through post-Fukushima measures derived from inspections after the Fukushima accident, and, the MACST (Multi-barrier Accident Coping Strategy) strategy has been established to maintain and restore essential safety functions in the event of extended loss of all AC power (ELAP) and loss of the ultimate heat sink (LOUHS).

The MACST strategy is mainly aimed at two functions: cooling water supply and power supply, and is performed using fixed and portable facilities.

In this study, a 1MW mobile diesel generator and a mobile low-pressure pump used in the MACST strategy are examined for their potential use in a seismic event to confirm their impact in terms of seismic risk using a PSA (Probabilistic safety assessment) model.

2. Methods and Results

2.1 MACST facilities

The MACST strategy consists of a three-step strategy as follows [1].

Table I: Step-by-step strategies in MACST

Phase	Strategy
Phase 1	Utilization of fixed facilities
Phase 2	Utilization of fixed & portable facilities available within 8 hours (1MW mobile diesel generator, mobile low-pressure pump, high-pressure mobile pump, etc.)
Phase 3	Utilization of fixed & portable facilities after 72 hours (3.2MW mobile diesel generator, high-capacity mobile pump, etc.)

In this study, the 1MW mobile diesel generator and mobile low-pressure pump used in the Phase 2 strategy are considered.

The 1MW mobile diesel generator (MDG) supplies emergency power to loads for ensuring plant safety in the event that the alternate AC diesel generator installed to cope with a station blackout is unavailable [2].

1MW MDG supplies 4.16 kV AC power and is normally stored in the storage building designed to be earthquake resistant. In the event of an ELAP, this facility is moved to the power plant, where it is connected to the 4.16 kV safety bus for train A or B to provide power. However, due to its limited capacity, the power supply is mainly used to maintain the natural circulation cooling of the reactor coolant.

Therefore, continuous heat removal operation using the steam generator is possible by charging the battery using a 1MW MDG before the battery is discharged. The battery is used as a power source for the turbine-driven auxiliary feed-water pump, which can inject cooling water into the steam generator after loss of all AC power.

The mobile low-pressure pump (MLP) can be used for injection into the reactor or steam generator and for filling of spent fuel pool in case of ELAP and LOUHS.

MLP is diesel-driven and does not require a power source. And it is stored in a storage building with the 1MW MDG.

Therefore, MLP can be considered as an alternate source for loss of the turbine-driven auxiliary feed-water pump.

In this case, MLP can be used after depressurizing the internal pressure of the steam generator using the main steam atmospheric dump valves (MSADVs) because the operating pressure of MLP is lower (20~30 kg/cm^2) than normal pressure of steam generator.

2.2 PSA model reflecting MACST facilities

In this study, a seismic PSA model was developed for the OPR1000, a representative nuclear power plant in Korea, considering 1MW MDG and MLP. In the PSA model for OPR1000, five accident scenarios were considered : seismic induced loss of essential power (SLEP), seismic induced loss of plant control system (SLOC), seismic induced small/large loss of coolant accident (SSLOCA/SLLOCA), seismic induced loss off-site power (SLOOP), and seismic induced general transient (SGTRN).

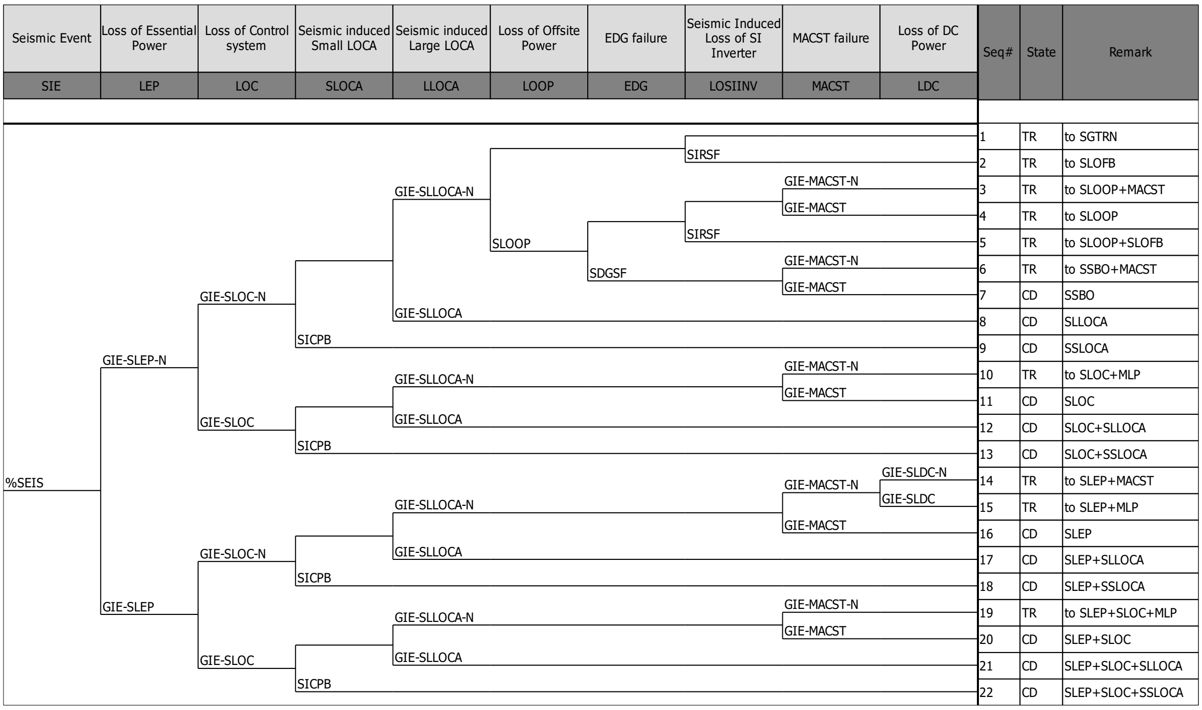

Fig. 1. Event tree of seismic induced initiating events for OPR1000 (with MACST facilities).

In the case of SGTRN, the seismic induced loss of feed and bleed operation (SLOFB) was additionally considered because bleed operation, which is the operation of opening the pressurizer safety relief valves, is impossible when the related inverters are damaged. And in the case of SLOOP, not only SLOFB, but also the seismic induced station blackout (SSBO) due to the damage of the emergency diesel generator was considered.

As the accident scenarios where 1MW MDG and MLP are available, secondary heat removal using these facilities was considered in the event of a station blackout accident in which the emergency diesel generator fails to operate after the occurrence of SLOOP, which is a representative ELAP event.

In addition, in the case of SLOC, which is one of the major accident scenarios in a seismic event, 1MW MDG was not considered because the turbine-driven auxiliary feed-water pump and all motor-driven components cannot be controlled. But, the secondary heat removal using MLP with manual opening of MSADV was considered.

Finally, SLEP accident can be caused by damage to five types of equipment as shown in Table II, most of which are required for battery charging by 1MW MDG. Therefore, the availability of 1MW MDG for each failure was reviewed, and it was assumed that the functional failures of 4.16kV switchgear and 480V load center, as well as the structural failure of 120V AC inverter, do not affect the power supply using 1MW MDG. MLP was considered in the same way as SLOC.

Event tree of seismic induced initiating events for OPR1000 considering 1MW MDG and MLP is shown in Fig. 1 and as an example, event tree for SLEP accident is presented in Fig. 2.

Table II: 1MW MDG application by SLEP-causing equipment

SLEP-causing equipment	Failure mode	1MW MDG application
4.16 kV Switchgear	Functional	O
	Structural	X
480V Load Center	Functional	O
	Structural	X
125V DC Cont. Center	Structural	X
Battery Charger	Structural	X
120V AC Inverter	Structural	O

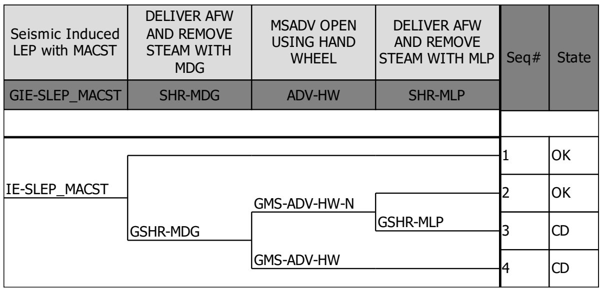

Fig. 2. SLEP Event tree for OPR1000 (with MACST facilities).

2.3 Results

Seismic induced failure events for the 1MW MDG and MLP were assumed to be the collapse of the storage building where these facilities are stored and the failure due to the collapse of the slope around the path of movement to the plant. As the fragility data for each event is not currently available, the fragility data as shown in Table III were applied assuming a HCLPF of 0.5g.

Table III: Seismic fragility data for MACST facilities

Event	A_m(g)	β_R	β_U	HCLPF
MACST storage building failure	1.46	0.3	0.35	0.5
Unavailability of movement due to the collapse of the slope	1.46	0.3	0.35	0.5

In addition to the seismic induced failure events, the probabilities of random failure events and human error events for each facility were considered as shown in Table IV. In case of human error probabilities, the PGA in seismic event were split into 4 bins, and different probabilities were applied to each bin.

Table IV: Failure events related to MACST facilities

Event	Prob.	Ref.
Random failure of 1MW MDG	2.91E-01	[3]
Random failure of MLP	4.06E-01	
Human error of 1MW MDG operation [bin1: 0~0.2g]	5.30E-02	[3], [4]
Human error of 1MW MDG operation [bin2: 0.2~0.4g]	5.98E-02	
Human error of 1MW MDG operation [bin3: 0.4~0.6g]	3.42E-01	
Human error of 1MW MDG operation [bin4: 0.6g~]	7.77E-01	
Human error of MLP operation [bin1: 0~0.2g]	5.01E-01	
Human error of MLP operation [bin2: 0.2~0.4g]	5.05E-01	
Human error of MLP operation [bin3: 0.4~0.6g]	6.54E-01	
Human error of MLP operation [bin4: 0.6g~]	8.83E-01	

As a result of the quantification using these data, it was showed that the seismic induced core damage frequency (SCDF) was reduced by 21.8% when 1MW MDG and MLP were considered.

When checking the impact of each accident scenario, 1MW MDG and MLP reduced the SCDF of SLOOP including SSBO by 52.6 %. For SLEP and SLOC, considering 1MW MDG and MLP, SCDFs of these events were reduced by 21.0 % and 20.1 %, respectively.

Although the SCDF for SLEP decreased less than that for SLOOP with SSBO, the impact of MACST facilities in SLEP is the largest in terms of seismic risk because SCDF is the highest in SLEP accident.

3. Conclusions

In this study, we examined the utilization of 1MW MDG and MLP among the portable facilities used in the MACST strategy in a seismic event to determine the impact on seismic risk using the PSA model. For this purpose, we reviewed the accident scenarios considered in the seismic PSA model and characteristics of MACST facilities, and 1MW MDG and MLP were considered not only for SLOOP, but also for SLOC and SLEP as an alternate source for secondary heat removal using steam generator. As a result, the overall frequency of seismic induced core damage was reduced by 21.8%. In terms of accident scenarios, the highest reduction rate was 52.6 % in the case of SLOOP including SSBO, but the reduction rate of 21.0 % in the case of SLEP had a greater impact on reduction of seismic risk because the proportion of SLEP in the overall SCDF is larger than that of SLOOP.

Therefore, it is expected that the safety of power plants in earthquakes will be improved with the introduction of MACST facilities, and in the future, the sufficient operating experience and analysis data will be used to determine the feasibility of using MACST facilities and reduce the uncertainties inherent in the model to produce realistic results.

ACKNOWLEDGEMENT

This research was supported by the National Research Foundation of Korea (NRF) Grant funded by the Korean government (MSIT) (No. RS-2022-00144425).

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