A Study on Automatic Seismic Trip System for Nuclear Power Plants

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1. Introduction

The frequency and magnitude of earthquake recently occurring in the world are gradually increasing. Earthquake is considered as a potential risk for safely operating a nuclear power plant (NPP). Some countries had already developed Automatic Seismic Trip System (ASTS) that automatically scrams nuclear reactor at the certain level of earthquake. Although one seismic monitoring system per 2 NPP units is being operated in Korea, there is not any system to automatically shut down nuclear reactor during a seismic event.

A lesson learned from Kashiwazaki-Kariwa NPP in the seismic event in July 2007 is the necessity of the ASTS in Korean NPP and initiated a study that aims at adopting the ASTS in operating NPP. This paper provides the technical backgrounds for developing Korean ASTS that include designing sensor, sensor box, trip logic cabinet, and actuation device and evaluating optimal ASTS configuration.

2. ASTS configuration

All of Korean NPPs in service are either pressurized water reactor (PWR) that includes Yonggwang, Kori and Ulchin NPPs, or heavy water reactor (HWR) that includes Wolsong NPP.

2.1 Configuration for PWR ASTS

PWR ASTS is composed of sensor, sensor box, trip logic cabinet, and Motor Generator Set (MG-Set) as described in Figure 1. In order to determine the optimal signal flow path for PWR ASTS, numerous ASTS configurations were reviewed and evaluated. The block diagram of Figure 1 was determined to be the most optimal configuration by considering both the result of reliability evaluation and the effect of design change for the existing system. MG-Set is the actuation device for PWR ASTS because it is considered the most proper system to shut down nuclear reactor concerning above two aspects.

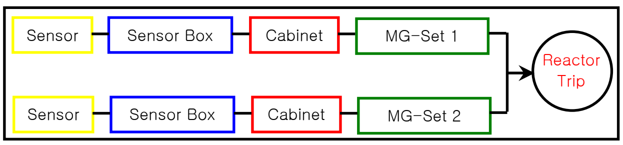

Figure 1. Optimal Signal Flow Path for PWR ASTS

As shown in Figure 2, the sensor is a triaxial accelerometer that consists of three accelerometers mounted orthogonally on an internal deck plate. The sensor box consists of band pass filter and V/I converter. The band pass filter is used for rejecting signal outside of 0.1 ~ 10 Hz. The V/I converter is a device to convert a signal from voltage to current for preventing voltage drop between sensor box and trip logic cabinet. The trip logic cabinet is divided into bistable logic and 2/4 coincidence logic.

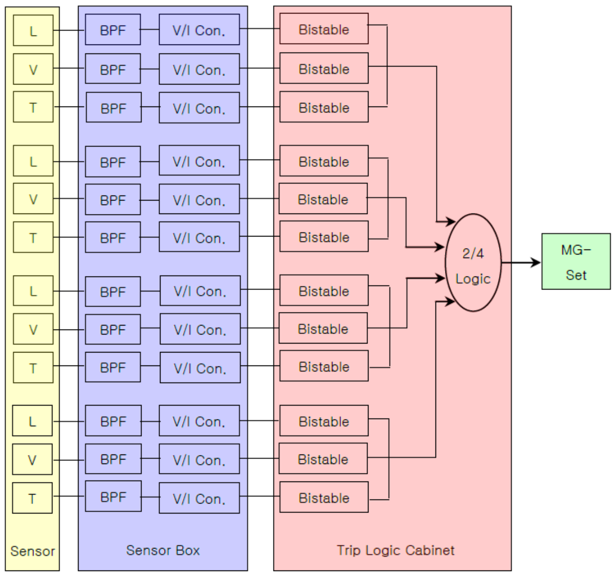

Figure 2. Block Diagram for PWR ASTS

2.2 Configuration for HWR ASTS

HWR ASTS is composed of sensor, sensor box, trip logic cabinet, and shutdown system (SDS) as described in Figure 3. The remaining part of HWR ASTS except for SDS is the same as PWR ASTS. Block diagram for HWR ASTS is also the same as PWR ASTS except for using SDS instead of MG-Set.

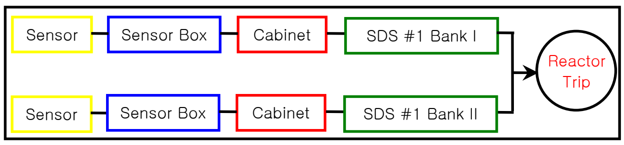

Figure 3. Optimal Signal Flow Path for HWR ASTS

3. Evaluation of Seismic Setpoint

3.1 Method for Error calculation

ASTS equipment to be considered in evaluating errors consists of sensor, band pass filter, V/I converter, and trip logic cabinet. The ASTS total channel error as depicted in equation (1) below is calculated by the combination of corresponding uncertainty factors of each ASTS equipment. The combination of each equipment uncertainty is performed by a conservative methodology that uses a summation in lieu of a square root sum of squares method.

$$\varepsilon_{ASTS} = \varepsilon_{Sensor} + \varepsilon_{Filter} + \varepsilon_{V/I\,converter} + \varepsilon_{Cabinet} \quad (1)$$

Sensor includes the error terms such as offset error, gain error, and cable error that have the characteristics of bias. Reference accuracy, drift, power supply effect, and temperature effect, etc. are considered as the error terms for band pass filter, V/I converter, and cabinet. The ASTS total channel error evaluated and assumed by the above method is 6.6 % span.

3.2 Method for Setpoint Determination

Peak ground acceleration (PGA) setpoints that do not exceed the design response spectrum were determined by considering crucial factors such as safe shutdown earthquake installation condition and site-specific vibratory ground motion. A fifth order Butterworth filter that senses low frequency seismic waves less than 10 Hz was simulated in evaluating PGA setpoints. Seismic sensors were assumed to be installed in the foundation of auxiliary building. Seismic waves were simulated by the method of random vibration theory in order to consider the characteristics of site-specific vibratory ground motion. PGA setpoints for Korean NPPs in service were evaluated as listed in the table 1. Figure 4 indicates where PGA setpoint is located on the PGA distribution.

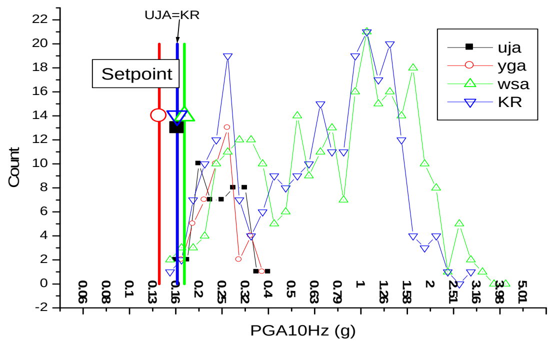

Figure 4. PGA Setpoints

Each ASTS setpoint is determined by a method that both ASTS total channel error and margin are subtracted from PGA setpoint. The ASTS total channel error of 6.6 % span is less than 0.1g. Therefore, the final ASTS total channel error including margin is assumed as 0.1g. ASTS setpoints for Korean NPPs in service were evaluated as listed in Table 1.

Table 1. PGA and ASTS setpoints

Site / Setpoint	Yonggwang NPP	Kori NPP	Ulchin NPP	Wolsong NPP
PGA(<10Hz) (Unit = g)	0.15	0.16	0.16	0.17
ASTS Setpoint (g) (Including error)	0.14	0.15	0.15	0.16

4. Evaluation of Effect on Power Grid System

The effect on power grid system by earthquake occurrence was evaluated. According to the evaluation, the power grid system is still able to maintain its stability when four NPP units are shut down simultaneously. However, when more than five NPP units are shut down at the same time, the power grid system incurs unstable state due to the unbalance of transmitting and receiving electrical power. The evaluation result indicates that the power grid system is required to maintain its stability by sequentially operating under-frequency relays.

5. Evaluation of ASTS Reliability

The reliability evaluation was performed for all kinds of available ASTS configurations. Although the ASTS configuration that includes reactor trip switchgear system (RTSS) as an actuation device results in the highest reliability, the configuration shown in Figure 5 was determined to be the optimal ASTS by considering both the result of reliability evaluation and the effect of design change for the existing system. The reliability of approximately 0.99833 is evaluated for the ASTS configuration that includes MG-Set as an actuation device.

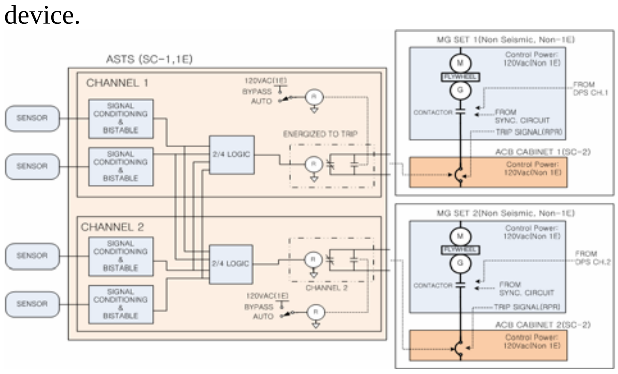

Figure 5. ASTS Functional Block Diagram

6. Conclusion

The evaluation results in this paper will be the bases for the ASTS that will be applied to the operating NPP in Korea.

REFERENCES

[1] IEEE 603, “IEEE Standard Criteria for Safety Systems for Nuclear Power Generating Stations", 1998.
[2] USNRC Reg. Guide 1.29, “Seismic Design Classification”, 2007.