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Operating Experiences of a Loss of Voltage Monitoring Program

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1. Introduction

Korea Hydro & Nuclear Power Company (KHNP) has established a systematic process to prevent unexpected loss of voltage (LOV) events as well as reinforced electrical system improvements since the Kori Unit 1 station blackout (SBO) in 2012. Despite these efforts, LOV events continue to occur due to inadequate work management and random human errors. On February 26, 2015, regulators analyzed the root causes of LOV events and presented the results for the nuclear industry [1]. Currently, KHNP uses a risk monitoring program, which is named “LOV Monitor”, for LOV prevention during pilot plant outages. This review introduces the operation experiences of LOV Monitor based on the evaluation results of a real event.

2. Operation Experiences of LOV Monitor

LOV Monitor tracks the open/close states of circuit breakers in the nuclear plant power systems and the maintenance work that can cause a LOV in the safety buses. Operators use LOV Monitor to evaluate the LOV risk during outage works before they authorize the works to proceed [2]. LOV Monitor had been developed for Hanbit Units 1 and 2 as pilot plants in 2013, and it passed a test operation during the twenty-first outage of Hanbit Unit 2 in 2014. Operators began to use LOV Monitor to permit outage works during the twenty-second outage of Hanbit Unit 1.

2.1. Test Evaluation History during a Real Event

At 13:57 on October 1, 2014, a real LOV event of safety power train A occurred due to maintenance crew errors in Hanbit Unit 2. Before the event, a functional test of the protection relays was in progress after the replacement of the power circuit breaker cubicles in the NA system, which is a 13.8 kV electrical power system [3].

Figure 1 presents a picture of LOV Monitor at one hour after the LOV event. During the event, emergency diesel generator A (EDG A) provided power to the bus because the LOV occurred on the 4.16 kV safety bus A. For power train B, startup transformer #2 and EDG B were out of service for outage maintenance. The blue lines in Figure 1 indicate the maintenance works in progress at the time of the event. Several maintenance works for buses and power circuit breakers were in progress according to the outage schedule of power train B. However, the tests after the replacement of the power circuit breakers in the NA system affecting power train A were in progress simultaneously according to the planned schedule.

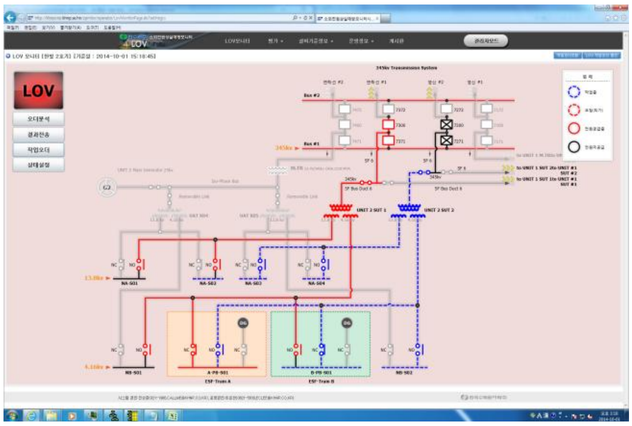

Fig. 1. LOV Monitor screen during the LOV event

2.2. Insights of the LOV Risk Evaluation

The LOV risk evaluation of the work order that caused the real LOV in Hanbit Unit 2 was conducted on September 22, 2014. At the time, the evaluation result indicated that the work order would cause a LOV. However, although all work on the energized power train was to be prohibited, the affected work order was authorized because the operators were notified by the electrical staff that the electrical isolation required in order to prevent an unintended LOV was implemented in advance. Figure 2 depicts the risk evaluation result using LOV Monitor and the reason for the exceptional authorization of the work.

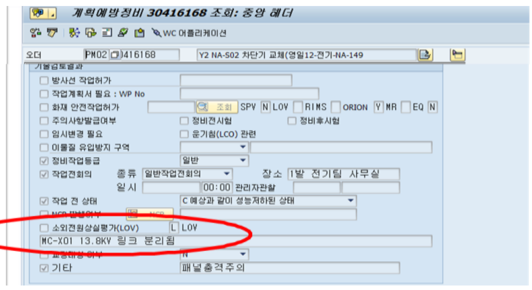

Fig. 2. Work order including the LOV risk evaluation result

The NA system bus and related circuit breakers were included as maintenance objects in the work order during the event. However, the test signal injection to the wrong current transformer (CT), which was a part-level component, resulted in the real LOV. In order to observe the effect of the maintenance objects in a work order, the objects for maintenance were selected differently for the simulated work orders in LOV Monitor.

Figure 3 and Figure 4 present the LOV risk evaluation results when the order included a NA system bus and a CT, respectively.

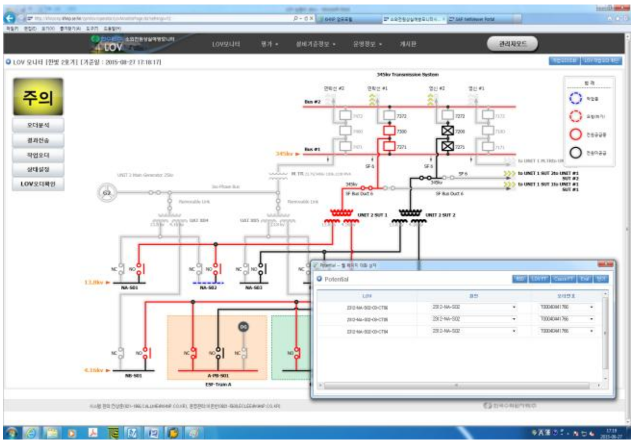

Fig. 3. LOV Monitor simulation when only a NA system bus was selected as the maintenance object

Figure 3 presents the result when the NA bus is selected as the maintenance object. The alarm on the monitor is “Alert” rather than “LOV”, and the CTs, which are installed above the NA system bus, are indicated as components that cause a LOV if their maintenance is initiated.

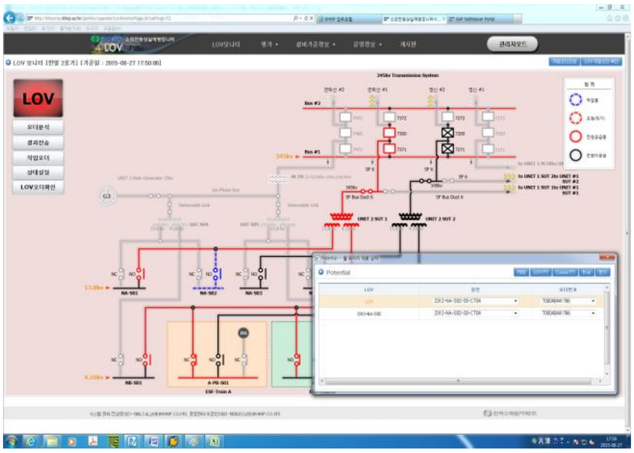

Fig. 4. LOV Monitor simulation when the CT between the bus and the circuit breaker in the NA system was selected as the maintenance object

Figure 4 presents the result when the CT between a circuit breaker and a bus in the NA system is selected as the maintenance object. The monitor alarm indicates “LOV”. This result explains the critical effect of the CTs that bypass the electrical isolation between the startup transformers and the circuit breakers in the NA system in order to prevent spurious LOV initiations during the replacement of the circuit breaker cubicles.

2.3. Improvements

Figure 1 demonstrates that startup transformer A provided power to safety bus B through the normal circuit breaker of train B. However, the alternative breaker for safety bus B was closed during the event. This false indication resulted from the maintenance of the circuit boards that are responsible for the open/close indication of the power circuit breakers for safety bus B. A manual open/close arrangement of incoming breakers for safety buses will be implemented in LOV Monitor. Otherwise, the indication circuit boards, which have been repaired in advance, will be installed before the main outage works.

For the work order preparation, the maintenance objects need to be selected with caution. When part-level components such as CTs are repaired or tested after authorization of work orders that only include major components such as buses, circuit breakers, and startup transformers as maintenance objects, the wrong protection devices that differ from the intended targets can be actuated to cause an unexpected LOV.

In addition, an outage schedule to prevent a LOV due to human error should be established and confirmed. Furthermore, operators and maintenance staff need to become accustomed to the authorization process of requests in order to evaluate the LOV risk.

3. Conclusions

The operation experiences of LOV Monitor in the pilot plants confirmed that this program could detect and reduce LOV possibilities from scheduling errors such as the simultaneous maintenance of energized trains and de-energized trains considering the physical conditions of the power circuit breakers.

However, a maintenance culture that heeds the risk monitoring result must be strengthened in order to obtain substantial effects through applying LOV Monitor to the outage. The maintenance staff should include part-level components such as CTs during their work order preparation. For user performance, operator training before each outage and system improvements for convenience needs to be implemented regularly.

References

[1] Workshop to Reflect Operating Experiences, KINS, 2015.
[2] Development of LOV Monitor, KHNP, 2013.
[3] LOV Event Investigation Report of Hanbit 1, KINS, 2015.