Transactions of the Korean Nuclear Society Autumn Meeting
Yeosu, Korea, October 25-26, 2018

Evaluation of EDG On-Line Maintenance Effect on Outage Schedule - Using OPR 1000 Standard OH Schedule

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1. Introduction

The availability is important for the performance of nuclear power plants (NPPs). The availability record of the U.S. NPPs has been excellent. For the 2017, the average availability of all US NPPs is 92.2% [1]. This is remarkable considering the age of NPPs in the U.S. One of the contributing factors for the excellent record is the on-line maintenance (OLM). The OLM is the preventive maintenance activity of safety equipment that is carried out during the operation.

Safety equipment are under the administrative control (Technical Specification). In the U.S., Nuclear Regulatory Commission pursued risk-informed performance-based regulation since early 1990s. The U.S. utilities applied the extension of the allowed outage times (AOT) under the risk-informed regulation (Risk-Informed Technical Specifications Initiative 4b) [2]. Examples are Vogtle LAR, Diablo Canyon, Lucie and Turkey Point [3]. The extension of AOT was the main vehicle for OLM of safety equipment in the U.S. Since it was introduced, OLM has proven to be beneficial not only in improving plant safety and equipment reliability, but also in improving the utilization rate of NPPs [4].

Realizing the benefit of OLM, some of European countries mandated N+2 requirements for safety equipment for new NPPs [5]. It requires an additional safety train on top of the single failure criterion. The additional safety train is used to satisfy the single failure criterion while performing OLM.

In Korea, a voluntary entrance into limiting conditions for operation (LCO) for the preventive maintenance of the safety system has not been allowed during the power operation [6]. However, we examined the effect on the outage (a. k. a. OH) for future application. Emergency diesel generator (EDG) was selected for this study since OH of EDGs had a large impact on the critical path of the OH schedule. Also, OLM of this system has been most widely performed in the U.S.

In this paper, we reviewed the one of OPR 1000 standard OH schedules. Then, we established a baseline OH schedule that included EDG additional tasks. With the baseline schedule, the OH reduction with OLM was examined. The effect of additional equipment to satisfy N+2 requirements was also examined.

2. EDG Maintenance in Outage

2.1 Standard OH Schedule for OPR 1000

For the NPPs in Korea, Standard Maintenance Procedure (Standard Maintenance-9680A) provides the key elements for OH schedule development. While making OH schedule, all tasks must proceed continuously without any delay unless there is a special reason. Major tasks that affect critical path are conducted 24 hours a day. Other tasks that do not affect critical path can be conducted 12 hours a day or 16 hours a day. For the standard OH schedule, reactor and refueling are on the critical path. Steam generator (S/G) maintenance, turbine and generator bearing / internals check are not on the critical path. Standard OH schedule based on the procedure is shown in Fig. 1.

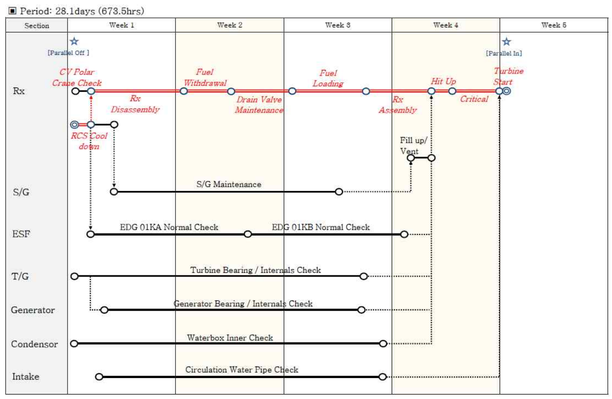

Fig. 1. Standard OH schedule

The standard OH schedule shows that the entire OH takes 28.1 days. However, most likely, there would be additional tasks affecting the OH period. Based on additional tasks, the critical path may be changed from reactor section to the S/G or the EDG. One example is the OH for EDG main bearing check and EDG piston replacement required for every 10th OH cycles.

2.2 Maintenance Effect of EDG for OH Schedule

The EDG manufacturer recommends EDG main bearing check and EDG piston replacement on every 10 cycles, respectively. These tasks become the critical path, because they affect the OH period.

We chose the actual OH schedule from one of OPR 1000 NPPs to develop a baseline schedule for EDG outage. As shown in Fig. 2 and Fig. 3, EDG main bearing check for both trains was performed in 2010 (12^{th} OH) and EDG piston replacement was performed in 2016 (16^{th} OH). Both of the tasks became critical path items. The 12^{th} OH took 32.5 days, while the 16^{th} OH took 60.3 days.

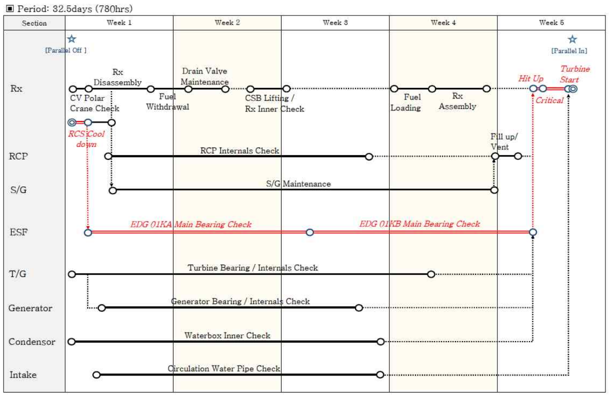

Fig. 2. OH schedule in 2010

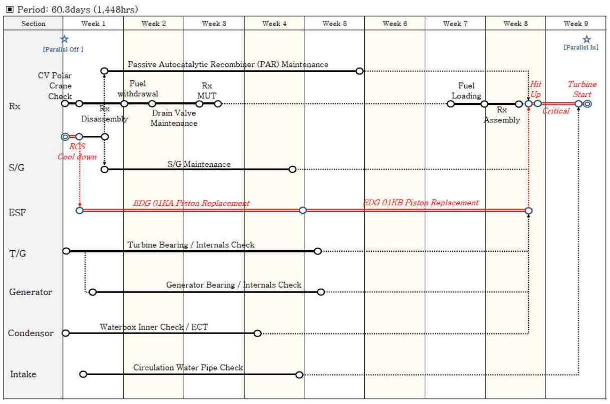

Fig. 3. OH schedule in 2016

2.3 Baseline OH Schedules with EDG Maintenance

In the case of the two OHs examined above, main bearing check for A and B trains was performed first (12^{th} OH) and then piston replacement for both trains was performed next (16^{th} OH). However, it is more desirable to perform OH for one item at a time both from safety and efficiency perspective. Fig. 4 shows the baseline OH schedule for main bearing check. The EDG tasks become the critical path and it adds 72 hours to the OH. Fig. 5 shows the baseline OH schedule for piston replacement. Again, the EDG tasks become the critical path and it adds 398.5 hours to the OH.

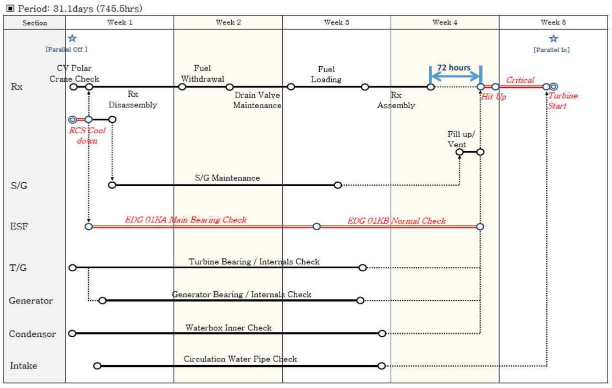

Fig. 4. Baseline OH schedule for EDG main bearing check

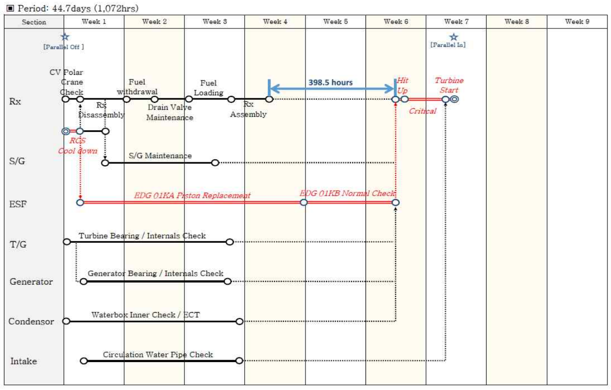

Fig. 5. Baseline OH schedule for EDG piston replacement

In developing baseline OH schedule from the actual schedule in 2010 and 2016, the tasks of the reactor section were changed to proceed continuously. S/G maintenance task and the turbine bearing / internals check were changed from 16 hours a day to 24 hours a day, since they became critical items. Reactor coolant pump internals check (12^{th} OH) and passive autocatalytic recombiner maintenance task (16^{th} OH) were special tasks performed for the specific plant. Since these are not generally included in OH tasks, they were not included in the baseline schedule.

3. Implementation of OLM

3.1 OLM Implemented based on Risk-informed regulation (RIR)

In the U.S., performing EDG outage by the voluntary entrance into LCO is allowed for preventive maintenance during the power operation. If we assume that EDG outage is performed online to domestic NPPs, the time added to the baseline OH schedule could be saved.

In order to examine the changes in OH period and their impact, we chose the time period of 20 years from 2019 to 2038. During the 20 years, EDG main bearing check will be performed for one train in 2024 (21^{st} OH) and the other train in 2026 (22nd OH). EDG piston replacement will be performed for one train in 2030 (25th OH) and the other train in 2032 (26th OH). As shown in Table I, the saved time would be 72 hours each for the main bearing check and 398.5 hours for piston replacement.

The economic impact can be estimated by multiplying each saved time by NPP electricity production per hour and electricity unit price. As shown in Table I, there were more than 5 billion Won benefits in 2024 and 2026, and over 33 billion Won in 2030 and 2032, respectively. When converted into the net present value (NPV) of 2018, the total benefit becomes 35 billion Won.

Assumptions used are,

1) Electricity unit price in relevant year is estimated by applying annual inflation rate of 3.0% on electricity unit price (55.87 Won/kW) in 2018 [7].

2) Annual discount rate of 7.0% is applied based on economic effect in the relevant year.

Since the annual inflation rate and the discount rate are point estimate values, there are uncertainties in the estimate.

Table I: The economic effect of OLM implementation based on RIR

Year	Saved time by OLM (hours)	Electricity production per hour (MW/h)	Electricity unit price in the relevant year (Won/kW)	Economic benefit based on RIR	
				In the relevant year (million Won)	In 2018 (million Won)
2024	72	1,050	66.71	5,043	3,360
2026	72	1,050	70.77	5,350	3,114
2030	398.5	1,050	79.66	33,332	14,800
2032	398.5	1,050	84.50	35,357	13,712
Total				79,082	34,986

3.2 OLM Implemented based on N+2 criterion

In some European countries such as Finland and UK, the N+2 criterion was applied to safety systems [5]. The N+2 criterion is to install an extra train to perform on-line maintenance while satisfying single failure requirement. With an additional train, building, equipment and maintenance cost for the added train will be incurred. The economic benefit of performing on-line maintenance for EDG while satisfying the N+2 criterion can be calculated by excluding the building, equipment and maintenance costs from the economic benefit of the above-mentioned the RIR based OLM. Fig. 6 shows the expenses and benefits. It was assumed that the building and equipment costs were incurred at the beginning of the project in 2012. Once operational, yearly maintenance cost is incurred. The maintenance costs include material costs such as main bearings and pistons.

The costs of the building, equipment and maintenance were also converted to 2018 by using NPV and summarized in Table Ⅱ.

Assumptions in the NPV calculation are,

1) Building and equipment costs: the inflation rate of 3.0% was applied to EDG building and equipment costs.

2) Maintenance costs: the inflation rate of 3.0% was applied to one OH maintenance cost of year 2016 to calculate the amount of 13 OH maintenance cost from 2019 to 2038. And, discount rate (3.0%) is applied based on the 13 OH maintenance cost from 2019 to 2038 in order to calculate the amount in 2018.

The benefit in this case would be 11.9 billion Won (NPV in 2018). Again, this is a point estimate and there are associated uncertainties.

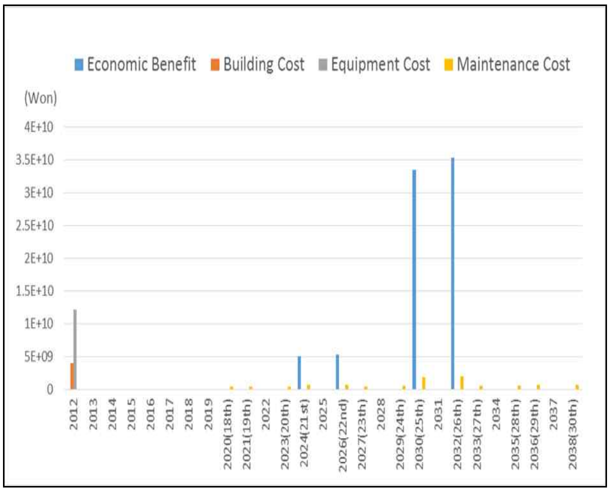

Fig. 6. OLM economic effect based on N+2 criterion

Table Ⅱ: OLM economic effect based on N+2 criterion

(Unit: million Won)

Economic effect by OLM in 2018	Building cost in 2018	Equipment cost in 2018	Maintenance costs in 2018 (13 times OH)	Economic benefit based on N+2
34,986	4,818	14,440	3,833	11,895

4. Summary

In this paper, the benefit of performing OLM on EDG was analyzed for OPR 1000 with two approaches. One approach is to apply AOT extension assuming it is allowed based on RIR, similar to the U.S. regulation. The other approach is to adopt N+2 criterion being used for new NPPs in Finland and UK. The result shows that OLM is useful in reducing OH for the two major EDG maintenance tasks for every 10 cycles.

The evaluation was based on 28 day standard OH schedule. In the U.S., the OH period is about 20 days. If we reduce the main critical path such as reactor, the impact would be greater. Furthermore, for NPPs with four EDGs, there would be substantial benefit of having OLM for the major EDG tasks.

ACKNOWLEDGMENT

This research was supported by 2018 Research Fund of the KEPCO International Nuclear Graduate School (KINGS), Republish of Korea.

We acknowledge the contribution of professor Ju-youl Kim in reviewing the paper and providing valuable comments.

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