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A Study on the Optimization Method of the Main Steam Safety Valve Characteristics for Overpressure Protection

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1. Introduction

The safety analysis on Loss of Condenser Vacuum (LOCV) event should be performed in accordance with Standard Review Plan (SRP) for pressurized water reactor. SRP is prepared for the guidance of staff reviewers in the office of nuclear reactor regulation in performing safety reviews of applications to operate nuclear power plants. The recent SRP requires that peak pressure in the primary and secondary system be evaluated separately since initial conditions are different for the primary and secondary systems [1]. If the LOCV event is applicable to recent SRP, the safety margins of the overpressure protection are reduced as compared with previous results. To improve the safety margin, it is needed to review the MSSVs which have an important role of the overpressure protection for the secondary side of the steam generators.

This paper presents an evaluation of the effect of the MSSVs characteristics with the analysis of LOCV event in order to have the sufficient safety margin of RCS and secondary system. This study has been conducted with the sensitivity analysis on the design parameters of MSSV which are the opening logic, set-point pressure and discharging capacity to the atmosphere.

2. Computational Analysis

2.1 Analysis methods and Assumption

The CESEC-III code is used to calculate peak pressure of RCS and secondary system during a postulated LOCV event in the APR 1400 Nuclear Power Plant (NPP). The CESEC-III code is primarily to describe the thermal-hydraulic transient behavior [2]. LOCV event is analyzed without the pressurizer spray flow with respect to RCS peak pressure. However, the maximum pressure of the secondary system is calculated with the assumption of an excessive spray flow. This assumption yields a conservative secondary peak pressure because the reactor trip on high pressurizer pressure is delayed by the spray flow.

2.2 Characteristics of MSSVs

When the pressure in a steam generator reaches set-point, the MSSVs commence discharging the internal fluid by a sudden opening called as popping [3, 4]. This means that the MSSVs are opened to mitigate the pressure build-up in the secondary system by relieving main steam during transient. For the typical valve characteristic curve of the MSSV [5], it shows “S type” stroke and takes about 100 milliseconds at most to full opening. Because it is impractical to realistically describe the typical valve characteristic curve with the time variation in the CESEC-III code, MSSVs are modelled such that it is opened with 70% of the total valve area at the set-pressure and then is fully opened at the 103% of the set-pressure.

3. Results and Discussion

In this work, the effect of the MSSV is evaluated from the viewpoints of opening logic, discharge capacity and opening set-point to reduce the RCS and secondary system peak pressure.

3.1 Opening logic of MSSVs

A sudden reduction in steam flow, caused by the LOCV, leads to a reduction in the primary to secondary heat transfer. The RCS pressure is increased by the reduction in the heat transfer. Figure 1 shows the variation of the RCS pressure with staggered opening logics of MSSVs such as 1/1/3, 2/1/2 and 3/1/1. The reactor trip occurs on the high pressurizer pressure at 5.79 seconds regardless of the variation of the MSSVs opening logic. The maximum RCS pressure in all cases is reached instantaneously after the opening of the 1st bank of MSSVs. After that, the RCS pressure decreases rapidly due to the combined effects of reactor trip and the opening of MSSVs. Analysis results show that the RCS peak pressure heavily depends on the 1st bank of MSSVs and the best opening logic of the MSSVs is turned out as 3/1/1. However, it has a little influence on the RCS peak pressure.

If LOCV occurs during the plant operation, the steam flow, which is produced by heat transfer between the primary system and secondary system, is discharged through turbine. However, the steam flow following a turbine trip transient is isolated by the closure of the turbine stop valves. The sudden reduction in steam flow leads to a dramatic increase in the pressure and temperature in the steam generators. The pressure behaviors in the steam generator with the opening logics of the MSSV are shown in Figure 2. The pressurization rate of steam generator decreases when the 1^{st} bank of MSSVs starts to open. However, steam generator pressure still increases because the steam discharge through only the 1^{st} bank of MSSV is insufficient. The steam generator pressure increase is suspended after the 2nd or 3rd bank of MSSVs open. In the cases of 1/1/3, 2/1/2, the peak pressure of the main steam system is limited to the set-point of the 3rd bank of MSSVs, and in the case of 3/1/1 it is limited to the set- point of the 2nd bank of MSSVs as shown in Figure 2. From the analysis results, it is known that the opening logic of MSSVs has large influence on the secondary system pressure and the opening logic 3/1/1 is most effective to decrease the secondary system peak pressure. Consequently, the opening logic of the MSSVs is very important to have the safety margin of the secondary system.

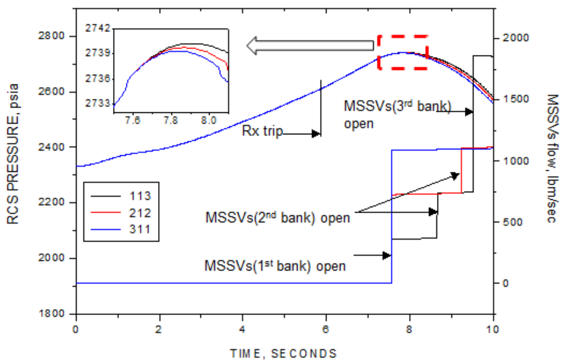

Fig. 1. RCS pressure with opening logic of MSSVs.

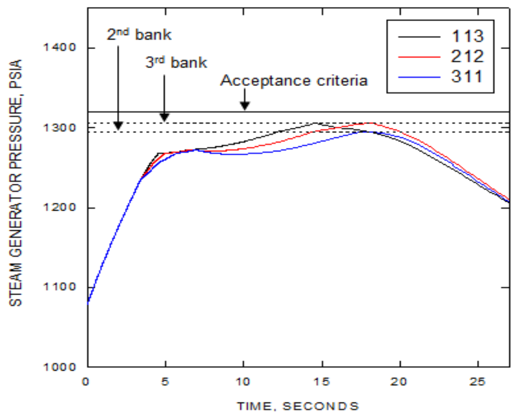

Fig. 2. Secondary system pressure with opening logic of MSSVs.

3.2 MSSVs capacity

The increase in the MSSV capacity can decrease the peak pressure of RCS and the secondary system. The maximum pressure of RCS occurs at around 7.8 seconds after the opening (7.6 seconds) of the MSSVs 1st bank regardless of valve capacity as shown on Figure 3. Eventually, MSSVs don't involve in decreasing the peak pressure of RCS due to no time difference between the occurrence time of RCS peak pressure and the opening time of the MSSVs.

The results in Figure 4 are the secondary system peak pressure which results in the sensitivity study of discharged capacity of MSSVs. The case 2 has the sufficient safety margin for the secondary system and fulfills the condition to capacity of already established products. Increasing the capacity of the MSSVs by 6 percent based on the case 1 resulted in an effect of 1.0 percent decrease in peak secondary pressure. If the capacity of MSSVs in case 3 is 6 percent greater than in case 2, the pressure of the secondary system is dramatically decreased by increased discharge of the steam in the steam generator. But, the case 3 does not fulfill the conditions to capacity of already established products in MSSVs. Consequently, case 3 has one disadvantage that it needs to be custom-made by the utility, which is economically infeasible.

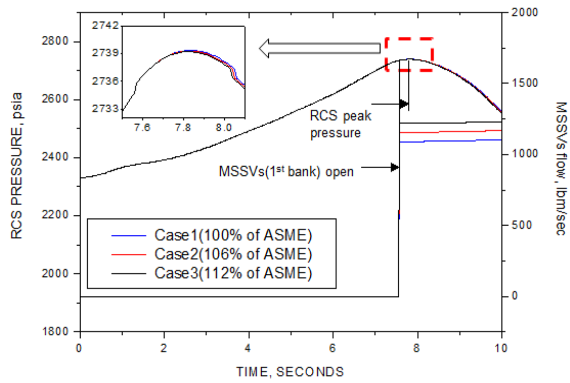

Fig. 3. RCS pressure with capacity variation of MSSVs.

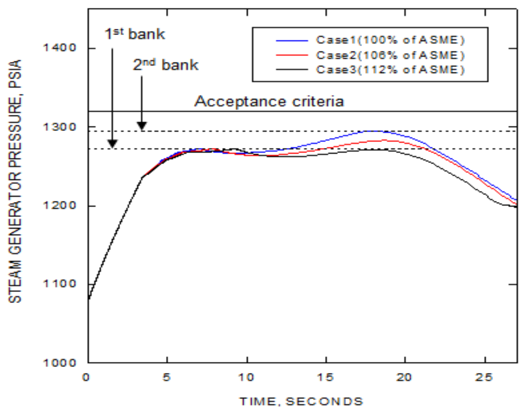

Fig. 4. Secondary system pressure with capacity variation of MSSVs.

3.3 Set-point of MSSVs

The set-point pressure of MSSVs is consistent with the ASME code requirements [6]. The set-point of the first bank must be at a pressure not exceeding the design pressure of the steam generator. Also, since MSSVs shall not be opened during normal operation of NPP, reducing the set-point pressure of the 1st MSSV bank is difficult. If the set-point pressure between the first bank and secondary bank is reduced, it is expected to decrease the peak pressure of the primary and secondary systems. Figure 5 shows the peak RCS pressure with the set-point variation of 2nd MSSV bank. RCS and secondary system peak pressures are normalized by the acceptance criteria. With MSSV opening logic 3/1/1, the set-point of 2nd bank MSSV in case 2 is at around 0.4 percent lower than in case 1, and about 0.8 percent lower in case 3 than in case 1. The peak RCS pressure has not been significantly influenced by MSSVs because pressure in a container does not reach the set pressure of 2nd MSSV bank. Eventually, the maximum pressure of RCS remains the same in all the cases because the reduced opening set-point of MSSV is not associated with RCS pressurization.

Figure 5 also shows the peak pressure of the secondary system with the variation of the set-point pressure of 2nd MSSV bank. The case 3 resulted in 0.5 percent decrease in secondary system pressure. As shown in Figure 5, the peak pressure of the secondary system does not decline proportionally as the set-pressure of 2nd MSSV bank decreases. Consequently, decrease in the opening set-point of MSSV would slightly aid the pressure mitigation capability for peak secondary pressure.

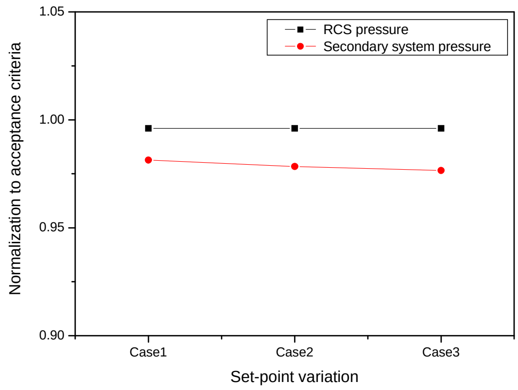

Fig. 5. RCS and secondary system pressure with set-point variation of MSSVs.

4. Summary and Conclusions

In this work, the effect of optimization method for the MSSV is evaluated from the viewpoints of opening logic change, discharge capacity increase and opening set-point decrease to mitigate the RCS and secondary system peak pressure resulting in additional safety margin. From the results, the optimization method is identified to be effective in reducing system peak pressure, especially for the secondary system. The opening logic which has increased number of MSSVs in the 1st MSSV bank remarkably decreases the pressure of the secondary system. In the cases of 1/1/3, 2/1/2, the peak pressure of the main steam system is limited to the set-point of the 3rd bank of MSSVs, and in the case of 3/1/1 it is limited to the set- point of the 2nd bank of MSSVs. Consequently, the opening logic of the MSSVs is very important parameter to have the safety margin of the secondary system.

The capacity and set-point of MSSVs do not involve increasing the peak pressure of RCS. The RCS peak pressure heavily depends on the 1st bank of MSSVs and the best opening logic of the MSSVs is turned out as 3/1/1. However, it has a little influence (about 1.0 psia) on the RCS peak pressure.

A solution to enlarge safety margin with respect to the system pressure under the strict regulation environment is found through this study. It is recommended that the new design method of MSSVs as shown in this study be adopted to have the sufficient safety margin of overpressure protection. And this can be used as a good technical background for the design modification of NPPs.

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