A Study on Development of Variable High Pressurizer Pressure Trip Function to Mitigate System Peak Pressure during Transients for Pressurized Water Reactors

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1. Introduction

According to intensified regulation environment such as separate safety analysis for the reactor coolant system (RCS) and the main steam system peak pressure [1], strict consideration of a control system malfunction as a single failure for the safety analysis and so on, the safety margin with respect to system pressure of pressurized water reactors (PWRs) has been decreased. Especially, when considering a loss of condenser vacuum (LOCV) event, safety margins for the RCS and the main steam system pressure become very small. Also, the possibility for that the main steam system pressure may violate the acceptance criteria during the LOCV event has been raised and relevant design modifications for the main steam safety valve (MSSV) have ever been performed as a solution.

In order to overcome this problem, in this work, the variable high pressurizer pressure trip (VHPPT) function has been developed and a feasibility study on the application of this trip function has been performed. The VHPPT function has been devised to trip the reactor beforehand when a sharply pressurizing transient such as the LOCV occurs and to cutoff system pressure increase, resulting in reducing the system peak pressure.

2. System Pressurizing Transients

There are many pressure increasing transients in PWRs. Among them, in safety analysis, several representative events such as the LOCV, a feedwater line break (FLB), a pressurizer level control system (PLCS) malfunction and so on are handled for the safety analysis report (SAR). Fig. 1 shows pressurizer (PZR) pressure variations from the initial condition during above mentioned pressurizing events at initial stage of each event. As shown in this figure, the pressurizing rate of the LOCV event is greater than 35 psi/sec and larger than that of any other pressurizing event. The pressurizing rate of the FLB event is about 10 psi/sec and that of the PLCS malfunction event is about 2 psi/sec. Therefore, the LOCV event can be distinguished from other events by pressurizing rate. That is, when the LOCV occurs, tripping the reactor beforehand by monitoring the pressurizing rate is possible.

On the other hand, as shown in Fig. 1, the pressurizing rate of the turbine trip event which has the steepest pressurizing rate among performance related design basis events (PRDBEs) approximates to that of the LOCV at initial stage of the event. That is, tripping the reactor for the LOCV by the pressurizing rate has possibility causing reactor trip during the turbine trip which is a PRDBE. However, as a requirement, the reactor trip shall not occur due to any PRDBE. Therefore, in order to prevent a reactor trip during the turbine trip event, another consideration to the trip function using the pressurizing rate above described is needed.

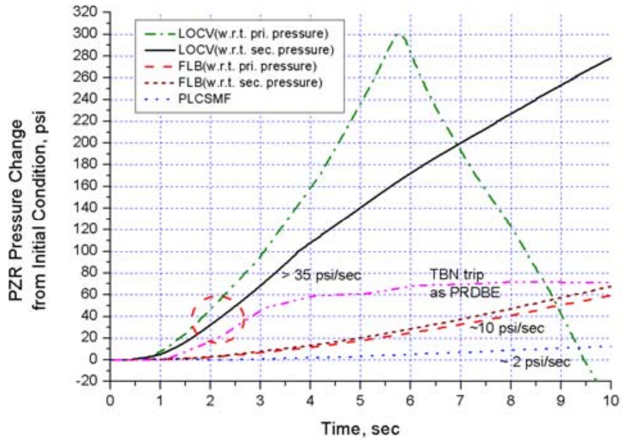

Fig. 1. PZR pressure variations from initial condition for pressurizing transients

3. Variable High Pressurizer Pressure Trip Function

In this work, the VHPPT function, which also includes the existing high PZR pressure trip (HPPT) function, is suggested. The VHPPT is developed such that it causes reactor trip when the indicated PZR pressure increases at a great enough rate during a sufficient time or reaches a high preset value. This trip function uses a rate-limited variable setpoint as similar way as the variable over power trip (VOPT) function currently used in existing PWRs. If the PZR pressure increases at a rate of change exceeding a preset rate of change and overtakes the VHPPT setpoint, the reactor trip occurs as shown in Fig. 2 and Fig. 3. In order to include the existing HPPT function, the high preset value above mentioned is determined as same as the existing HPPT setpoint, as shown in Table I. Also, a sufficient time for the indicated PZR pressure to overtake the VHPPT setpoint is considered to prevent the reactor from trip during the turbine trip event as a PRDBE. This time is implemented by the step setpoint which is added to the current indicated PZR pressure value to calculate the VHPPT setpoint. Since, during the turbine trip as a PRDBE, the steam bypass control system (SBCS) and the reactor power cutback system (RPCS) may operate and suspend system pressurizing as shown in Fig. 1, an appropriate selection of the step setpoint can prevent reactor trip.

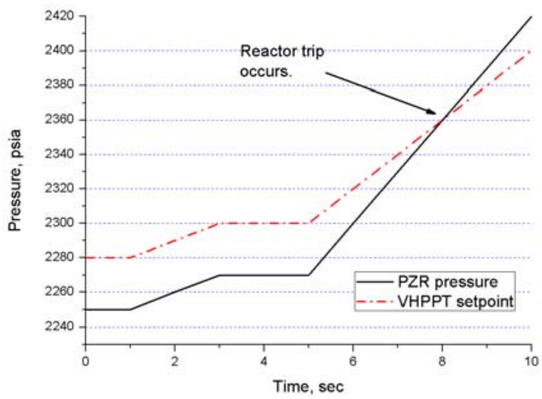

Fig. 2. Trip occurring case I by VHPPT

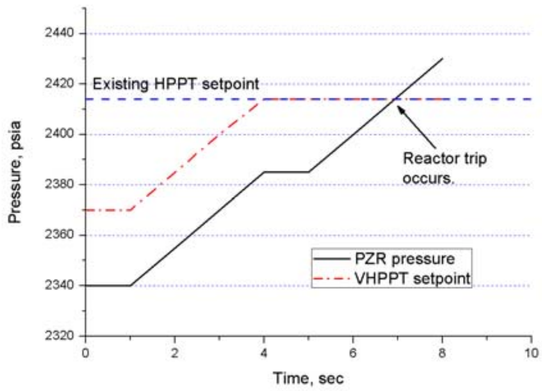

Fig. 3. Trip occurring case II by VHPPT

In this work, as shown in Table I, the setpoint rate of change and step setpoint for the VHPPT have been determined intuitively as 20 psi/sec and 30 psi, respectively through several simulation experiments.

Table I: VHPPT setpoints

High preset	Existing HPPT setpoint
Rate limit	20 psi/sec
Step	30 psi

4. Application Results and Discussions

The developed VHPPT function has been applied to the pressurizing event analysis and the effect has been investigated. The reference plant is the APR1400 and the LOCV which is one of the most pressurizing event above mentioned is chosen as the target event. In order to obtain conservative results, the maximum HPPT setpoint with uncertainty which has been applied in the safety analysis is considered. In analyses, thermal hydraulic behaviors of transients are calculated using the CESEC-III computer program [2].

4.1 Analysis with respect to RCS Peak Pressure

Under the most limiting initial condition with respect to the RCS peak pressure for the LOCV event, the RCS pressure variations according to time with and without application of the VHPPT function are shown in Fig. 4.

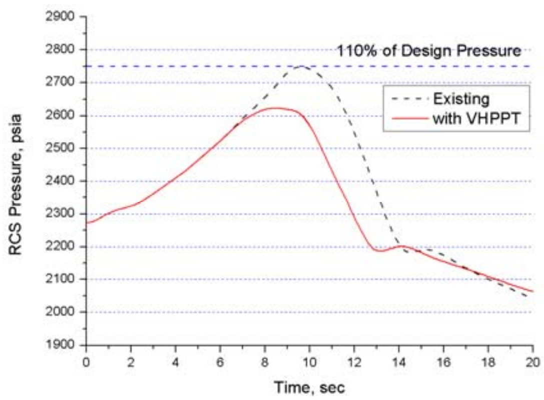

Fig. 4. Comparison result with respect to RCS peak pressure

For the existing case, that is, without application of the VHPPT function, the RCS (RCP discharge) peak pressure is 2746.85 psia at 9.58 seconds after the event initiation. During this transient, the reactor trip occurs at 7.66 seconds after the event initiation by the HPPT. With application of the VHPPT function developed in this work, the RCS peak pressure is 2623.00 psia at 8.39 seconds after the event initiation. During this transient, the reactor trip occurs at 4.54 seconds after the event initiation by the VHPPT. Due to application of the VHPPT function, the reactor trip during the LOCV event is advanced by 3.12 seconds resulting in the RCS peak pressure decrease by 123.85 psi. Consequently, by the VHPPT function, 123.85 psi of the additional safety margin with respect to the RCS pressure has been obtained.

4.2 Analysis with respect to Main Steam System Peak Pressure

Under the most limiting initial condition with respect to the main steam system peak pressure for the LOCV event, the main steam system pressure variations according to time with and without application of the VHPPT function are shown in Fig. 5. Differently from the analysis with respect to the RCS pressure, the excessive spray flow is considered as a single failure because this excessive spray flow may postpone the HPPT and enlarge heat amount transferred from the RCS to the main steam system resulting in adverse effect on the main steam system pressure. For the existing case, that is, without application of the VHPPT function, the main steam system peak pressure is 1319.52 psia at 15.47 seconds after the event initiation.

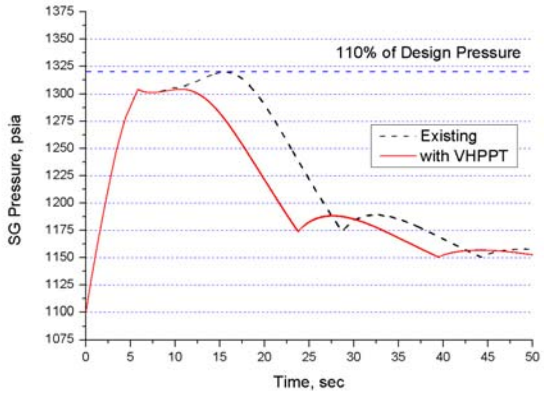

Fig. 5. Comparison result with respect to main steam system peak pressure

During this transient, the reactor trip occurs at 8.91 seconds after the event initiation by the HPPT. With application of the VHPPT function, the main steam system peak pressure is 1304.44 psia at 10.55 seconds after the event initiation. During this transient, the reactor trip occurs at 4.45 seconds after the event initiation by the VHPPT. Due to application of the VHPPT function, the reactor trip during the LOCV event is advanced by 4.46 seconds. This earlier reactor trip decreases the main steam system peak pressure by 15.08 psi. Consequently, it can be known that, by the VHPPT function, 15.08 psi of the additional safety margin with respect to the main steam system pressure has been obtained.

4.3 Validation for Turbine Trip as a PRDBE

As mentioned above, the reactor trip by the VHPPT function shall not occur during the turbine trip event which has the steepest pressurizing rate among PRDBEs. Fig. 6 shows the VHPPT setpoint variation during the turbine trip event. As indicated in this figure, the PZR pressure during the turbine trip does not exceed the VHPPT setpoint and the reactor trip does not occur. This is due to a suitable step setpoint for the VHPPT which secures a sufficient time for the indicated PZR pressure to overtake the VHPPT setpoint.

5. Conclusions and Further Studies

In this work, the VHPPT function has been suggested and developed to trip the reactor beforehand and to cutoff system pressure increase mitigating the system peak pressure of PWRs when a sharply pressurizing transient like the LOCV occurs. The VHPPT function uses the rate-limited variable setpoint and includes the existing HPPT function. Also, it additionally utilizes the step setpoint. From the analysis results with the VHPPT function, it is turned out that this VHPPT function remarkably reduces the system peak pressure. Also, it is identified that the reactor trip does not occur during the turbine trip as a PRDBE.

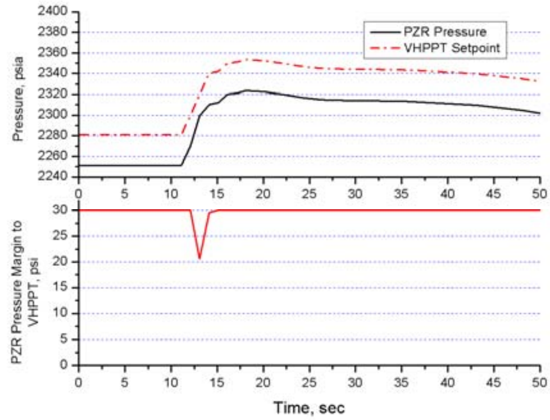

Fig. 6. PZR pressure and VHPPT setpoint variation during turbine trip event as a PRDBE

Setpoint values of the VHPPT function have been determined intuitively through several simulation experiments in this work. The optimization of these setpoint values in order to improve the VHPPT function and identifying the applicability of the VHPPT function to actual PWRs from the viewpoint of implementation in the plant protection system remain as future works.

REFERENCES

[1] NUREG-0800, "Standard Review Plan(SRP) for the Review of Safety Analysis Reports for Nuclear Power Plants," March 2007.
[2] "CESEC Digital Simulation of a Combustion Engineering Nuclear Steam Supply System," CENPD-107, April 1974.
[3] “SKN 3&4 Final Safety Analysis Report,” Rev.01, November 2015.