Accident Analyses of Optimal Designed Primary Loop

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Abstract. Through optimizing the operational and the structural parameters, the weight, volume or the efficiency, etc of primary loop can be improved. To study the transient behaviours of the optimal scheme under designed based accidents, we use RELAP5 code to build simulation model of the primary loop, and set conservative boundary conditions and initial conditions to make simulations of loss of feed water accident and station blackout accident for both of the optimal scheme and the prototype. The study shows that the core safety can be guaranteed under the accidents.

1. Introduction
For engineering problems, the cost can be reduced and the efficiency can be increased by optimizing the design scheme. In the area of nuclear engineering, the optimization methodology is widely employed. Engineers benefit from this method in the design of core shield (Ref.[1]), the design of reactor core(Ref. [2]), refueling(Ref.[3]), maintenance schedule(Ref.[4]), etc..

In recent years, optimization methodology has been gradually used in the weight or volume optimal design of the nuclear power plant (Ref.[5], Ref.[6]), but the safety ability of the proposed optimal scheme is questioned. Hence, it is necessary to study the transient behaviours of the optimal scheme under designed based accidents. In this research, the RELAP5 models for Qinshan-I nuclear power plant and one of its optimal schemes are built, and the boundary conditions, initial conditions are set to compare the safety ability of the optimal scheme and its prototype.

2. The Optimal Scheme
The optimal scheme is represented by a combination of the coolant pressure(P1), the reactor inlet temperature(Tin), the reactor outlet temperature(Tout), the inner diameter of the pressurizer(DP), U-tube outer diameter of the steam generator(dcs), the tube-pitch ratio of the steam generator(s/dcs), the coolant velocity in the U-tube(v), which are optimal variables. The parameter combinations for both the optimal scheme and the prototype are depicted in TABLE 1.

| Parameter combinations for optimal scheme and its prototype |
|----------------------------------------------------------|
| Parameter      | Optimal Scheme | Prototype |
|----------------|----------------|-----------|
| P1 (MPa)       | 14.8           | 15.2      |
| Tin (℃)        | 286.99         | 288.8     |
| Tout (℃)       | 313.48         | 315.2     |
| DP (m)         | 2.56           | 2.5       |
| dcs (m)        | 0.0205         | 0.022     |
| s/dcs          | 0.0205         | 0.022     |
| v (m/s)        | 1.264          | 1.41      |

Based on the variables in TABLE 1, the primary loop of Qinshan-I nuclear power plant is separated into nodes for simulation, which is depicted in FIGURE 1. For both the Qinshan-I nuclear power plant and its optimal scheme, the simulation code are established.
Before accident analysis for the optimal scheme, it is necessary to develop its operating regulations. Based on the actuating signals of the prototype, the actuating signals of the optimal scheme are formalated by Eq. (1)

$$S'_o = \frac{S'_p}{S'_o} S'_w$$

(1)

Where, $S'_p$, $S'_w$ represent the rating signals of the prototype and the optimal scheme, respectively (such as: pressure, water level, etc.). $S'_p$, $S'_w$ represent signal trigger values of the prototype and the optimal scheme, respectively. If the monitored signal reaches its trigger value, related components will be acted.

3. Accident Analyses

3.1. Loss of feed water accident

In this accident analysis, the follow supposed conditions are given out:

(1) The steam generators lose feed water when the primary loop has run 10s in steady way.
(2) The reactor control rods start falling 2s later when the scram signal is triggered.
(3) The steam isolation valve is supposed closed, and the steam in the steam generators is discharged into air by the relief valves.
(4) The emergency feed water is provided when the feed water has been lost 60s.

In this simulation, the primary loop runs at 100% full power. Then, the feed water of the steam generators are stop. The signal, mismatching of flow rate of steam and feed water, which is a necessary condition for reactor shut-down is triggered. The water level in steam generator decreases sharply, and the scram signal is triggered when the signal of “water level low” is reached. The emergency feed water is provided when the feed water has been lost 60s. The liquid in the second side of the steam generators change to steam, and the pressure in the second side increases gradually. When the pressure release pressure is reached, the steam is discharged into air. In this way, the decay heat of the reactor core is brought out.

FIGURE.2-FIGURE.4 depict the variations of important parameters in this process. It can be concluded that the core safety can be ensured in this accident.
FIGURE 2. The variations of pressures under loss of feed water accident.

FIGURE 3. The variations of temperatures under loss of feed water accident.

FIGURE 4. The variation of the fuel centerline maximum temperature under loss of feed water accident.

3.2. Station blackout accident

In this accident analysis, the follow supposed conditions are given out:

1. The steam generators lose feed water when the primary loop has run 10s in steady way.
2. The reactor control rods start falling 2s later when the scram signal is triggered.
3. The steam isolation valve is supposed closed, and the steam in the steam generators is discharged into air by the relief valves.
(4) The emergency feed water is provided when the feed water has been lost 60s. In this simulation, the primary loop runs at 100% full power. Then, the station blackout occurs. The scram signal is triggered 2s later. The emergency feed water is provided when the feed water has been lost 60s. The liquid in the second side of the steam generators change to steam, and the pressure in the second side increases gradually. When the pressure release pressure is reached, the steam is discharged into air. In this way, the decay heat of the reactor core is brought out.

FIGURE.5 depict the variations of important parameters in this process. It can be concluded that the core safety can be ensured in this accident.

![FIGURE5. The variation of the main parameters under station blackout accident](image)

### 4. Conclusions

In this work, the RELAP5 code is used to obtain the transient behaviours for the primary loop of Qinshan-I nuclear power plant and its optimal scheme, under loss of feed water accident and station blackout accident. It can be concluded that the safety of the optimal scheme can be guaranteed under these two accidents.

### References

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