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Development of Real-time RCS Flow Rate Calculation and Monitoring Technology for APR1400

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1. Introduction

Nuclear power plants measure the primary coolant flow monthly using heat balance method to ensure that it is within the operating limits of technical specification. The lower limit of the primary coolant flow rate is set to ensure adequate thermal margin for the core and the upper limit is set to maintain mechanical integrity of the reactor vessel components.

The most accurate measured flow at nuclear power plants is obtained through mass flow measurements made by heat balance method. The Core Operating Limit Supervisory System (COLSS) calculates the flow rate in real-time, which must always be less than or equal to the monthly measured mass flow rate. The Core Protection Calculator (CPC) also calculates the flow rate in real time based on the Reactor Coolant Pump speed and must always be less than or equal to conservatively than the calculated flow rate from the COLSS. To enhance thermal margin during normal operation, real-time Reactor Coolant System (RCS) flow rate calculation and monitoring technology using Plant Information (PI) system data has been developed.

2. Methods and Results

2.1 Flow Limit of Technical Specification

The uncertainty of mass flow rate measurement by heat balance method is about 3.14% at full power. The technical specification limits the mass flow rate considering the uncertainty of flow rate measurement. And the uncertainty of COLSS flow calculation is about 4.2%, and appropriate monitoring should be conducted considering the uncertainty in calculated flow rate during normal operation. [Fig.1]

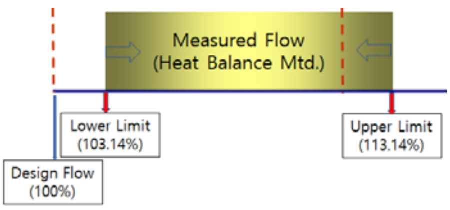

Fig. 1 RCS Mass Flow Rate Limit (T/S)

2.2 Real-time Mass Flow Calculation Method

The hot-leg and cold-leg temperature in the primary system using the real-time Plant Information (PI) system should be acquired during the steady state conditions. At the same time, the most accurate plant secondary power (BSCAL), should be acquired. The mass flow rate of the Reactor Coolant System (RCS) is calculated using the enthalpy rise of the hot and cold leg and the secondary power (BSCAL). [Eq. (1)]

Measured RCS Mass Flow
= 3,983(MW) x 859,845(kcal/hr/MW) x Power Fraction/Enthalpy rise(kg/kcal) ----------------(1)

2.3 COLSS Flow Calculation Method

The COLSS uses the RCP pressure drop and specific volume to determine the RCP head and then COLSS flow (GPM) is calculated using pump performance coefficients and pump speed. [Fig.2] [Eq. (2), (3)]

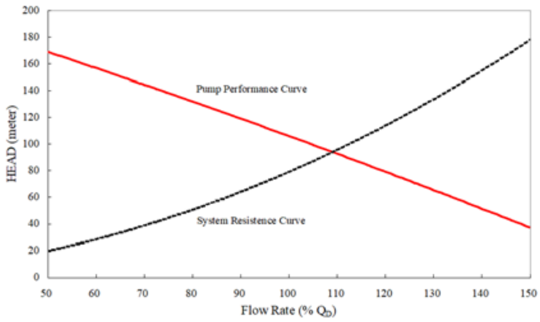

Fig. 2 Generic Curve of RCP Head vs. Flow

Head = 144 × PDP × RCSV --------------------------- (2)
where,
Head = Head of Pump
PDP = Differential Pressure of Pump
RCSV = Specific Volume of Pump Fluid

MFLOW = (GPM/RCSV) × 8.020833 ----------------- (3)

where,
MFLOW = COLSS Mass Flow(lbm/hr)

2.4 CPC Flow Calculation Method

The Core Protection Calculator (CPC) calculates flow rates in real-time using the Reactor Control Power (RCP) speed and periodically adjusts the flow calibration constant (FC1) for accuracy of the primary power (BDT). [Eq. (4), (5)]

$M = (N/V) \times Funct\ (Th)$ ----------------------------------(4)

where,

M = Normalized CPC Flow
N = Normalized Pump Speed
V = Normalized Specific Volume

$MC = FC1 \times M$ --(5)

where,
MC = Normalized Calibrated Mass Flow Rate
FC1 = CPC Flow Calibration Constant

2.5 Application of Real-time RCS Mass Flow

Recently, as the core loading pattern is optimized, hot leg streaming phenomenon is becoming increasingly severe. Hot leg streaming refers to the presence of non-uniform temperature profiles in a pressurized water reactor (PWR) hot leg due to non-uniform flux and flow distribution in the core. Hot leg streaming phenomenon causes hot leg temperature to be measured higher than actual, resulting in underestimating the reactor coolant flow rate. In addition, if secondary feedwater fouling occurs, the secondary power (BSCAL) will be highly indicated, resulting in overestimation of the reactor coolant flow rate. Therefore, real-time monitoring of the reactor coolant flow rate can be used as a means to indirectly prediction of hot leg streaming and feedwater fouling phenomenon.

3. Conclusions

The primary coolant flow rate is required to be measured monthly in accordance with technical specification and is an extremely important operational parameter for monitoring the thermal margin of the nuclear power plant. If the operation of reactor is normal, the primary coolant flow rate should maintain a constant value. The occurrence of hot leg streaming and feedwater fouling phenomenon can be indirectly confirmed by real-time monitoring of the primary coolant mass flow rate. By developing a technology to calculate and monitor the primary coolant mass flow rate in real time using the Plant Information (PI) system, significant contributions will be made to the diagnosis of abnormal core and safe operation of the nuclear power plant.

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