An Implementation of Main Steam Flow-Based Calorimetric Power Measurement for Yonggwang Nuclear Power Plant Unit 4

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1. Introduction

Most of pressurized water reactors have used a steam plant calorimetry, which is based on the process of performing a heat balance around the steam generators, to determine core thermal power. The differential pressure across a venturi installed in the feedwater flow path is a key element in the calorimetric measurement.

Many plants have experienced fouling phenomena caused by mainly corrosion products building up on the meter's venturi or orifice [1]. The fouling increases the measured differential pressure across the meter, which in turn results in an overestimation of the flow rate. Consequently, the core thermal power is also overestimated. To maintain the reactor power below the regulatory licensing power, the plants have to be derated.

To overcome this degraded thermal performance, a main steam flow-based calorimetric power calculation methodology has been developed [2] and implemented for determining core thermal power at the Yonggwang Nuclear Power Plants which are leading plants for the new calculation method implementation.

In this paper a brief description of the power calculation theory and its implementation algorithm in the plant computer system are presented together with the testing results of Yonggwang Nuclear Power Plant Unit 4 (YGN4).

2. Theory and algorithm

In this section steam flow and steam generator power equations are briefly described. A brief description of implemented algorithm and main steam flow calibration is presented.

2.1 Calculation theory

The mathematical mass flow equation for the main steam flow-based secondary calorimetric power (MSBSCAL) [2] is similar to that for the main feedwater flow-based secondary calorimetric power (FWBSCAL) using ASME theory [3].

$$W_{MS} = K\left(\frac{Y \cdot d^2 \cdot F_a}{\sqrt{1-\beta^4}}\right)\left(\sqrt{\rho_s \Delta P}\right)(MSCF) \quad (1)$$

The measured pressure differentials across the steam nozzles are averaged for each steam generator.

The heat and flow balances across the steam generator are schematized in Fig. 1, where miscellaneous heat losses and gains are neglected. Each steam generator power is calculated as shown in Eq. (2).

$$Q_{SG} = W_{MS}h_{MS} - (W_{MS} + W_{BD})h_{FW} + W_{BD}h_{BD} \quad (2)$$

The final core thermal power is calculated to be the sum of steam generator powers with system heat gains and losses considered [2].

$$Q_C = \sum Q_{SG} + \text{Loss and Gain} \quad (3)$$

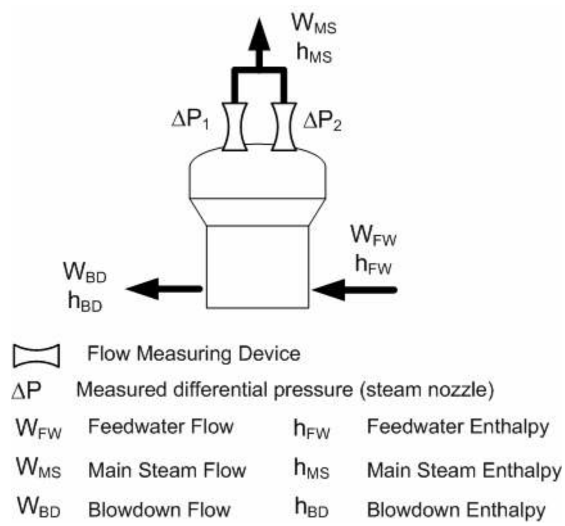

Fig. 1. A flow and heat balance schematic

2.2 Algorithm implementation

The mathematical main steam flow and steam generator power equations are implemented in the computer system called COLSS (Core Operating Limit Supervisory System). The schematic algorithm is shown in Fig. 2. The added calculation module is independent of and parallel with the existing power calculation module (FWBSCAL). Two power indicators (FWBSCAL and MSBSCAL) are continuously calculated and indicated online, one of which is selected for monitoring or periodic calibrating other powers such as neutron flux power.

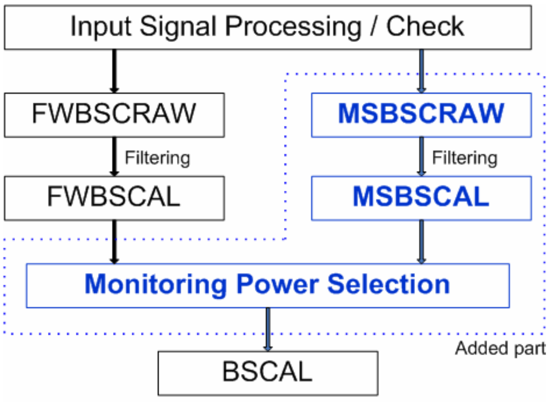

Fig. 2. COLSS algorithm schematic

2.3 Main steam flow calibration

Since the existing venturies in the SG steam nozzles have not been calibrated at the laboratory, calibration tests are needed at the site, more specifically for each initial or reload cycle operation. Measured steam flow rate is compared with the measured feedwater flowrate, and the main steam calibration factor (MSCF) is determined. The calibration test is carried out during the startup period when all the venturies are cleaned and thus the feedwater venturi fouling effect is minimal.

The calibration testing conditions are as follows:

- Early stage of each cycle operation
- Nearly 100 % power operation
- Steam generator blowdown secured
- Data acquisition for minimum 3 hours

The main steam calibration factor is newly determined by the following equation for each steam generator for each operation cycle:

$$\frac{MSCF_{NEW}}{MSCF_{OLD}} = \frac{\text{Measured feedwater flow rate}}{\text{Measured steam flow rate}}$$

The measured feedwater and steam flow rates are processed for noise elimination before used in the factor calculation.

3. Testing results

The main steam calibration testing was performed at YGN4 (Cycle 11). The main steam calibration factors obtained are as follows and were put into the COLSS system via addressable constant settings:

SG 1	0.9793
SG 2	0.9799

The Fig. 3 shows the power performance before and after the calibration setting. Before the calibration setting the main steam flow-based power shows about 2% higher than the conventional feedwater flow-based one. After the calibration setting two powers show a nearly consistent behavior with some different variances. The main steam flow-based power shows a little larger variance in the scatter as expected.

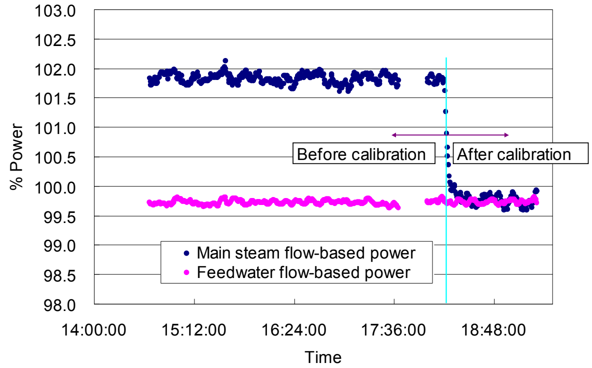

Fig. 3. Thermal power performance

4. Recommendation

The implementation at YGN4 is a leading application and a long-term calorimetric performance data need to be collected and evaluated. This operating experience will provide reliability data supplementing the application of main steam flow-based secondary calorimetry and motivate the introduction of the new calorimetry to other plants.

NOMENCLATURES

K	Unit conversion constant
W	Mass flow rate
Y	Steam compression factor
F_a	Area thermal expansion factor
d	Diameter of venturi throat
β	the ratio of venturi throat diameter to downstream pipe diameter
ΔP	Average value of measured differential pressures across the steam nozzles
ρ_s	Density of flowing steam with steam quality considered
MSCF	Main steam calibration factor
Q	Thermal power
SG	Steam generator

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