Development of an advanced reactivity computer interface circuit for Ex-core Neutron Flux Monitoring System

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1. Introduction

Ex-core Neutron Flux Monitoring System(ENFMS) of a PWR measures neutron flux based on escaping neutrons from a reactor core and transmits this neutron flux to the reactor protection and monitoring system.[1] The ENFMS consists of safety channels, control channels and start up channels. The control channel of the ENFMS provides the reactivity computer with signals for Low Power Physics Tests (LPPTs) after fuels loading.[2] In general, the accuracy of wide range current meter used in the reactivity computer is very low. Therefore, the wide range current meter is not suitable for measurements of low level current (below nano ampere) produced in the control channel during LPPTs. In addition, the wide range current meter creates large reactivity perturbations due to the dead time generated during input range changes.

In this study, a Reactivity Computer Interface Circuit(RCIC) is developed by utilizing the current mirror in order to reduce noises generated during current signal measurement. Consequently, the RCIC enhances the accuracy of reactivity calculation. The excellency of this RCIC was verified by performing a series of experiments carried out at the AGN-201K reactor in KyoungHee University.

2. Method and Results

A design method for the RCIC of control channel, algorithm of reactivity calculator computer, and their results for a series of experiments carried out at the AGN-201K reactor are described in the followings.

2.1 RCIC Design Method

As shown in the Fig. 1, the RCIC consists of current mirror and two I-V converters. Current signals obtained from the UIC for control channels are fed to the current mirror and then the current mirror diverges two currents with the same value.

The diverged currents are converted to voltage signals through High Gain I-V Converter(HGIV) and Low Gain I-V Converter(LGIV).

As can be seen in the Table 1, HGIV has conversion gain of 100 mV/nAmp and LGIV has conversion gain of 10 mV/nAmp. The output voltage signals of two I-V converters are designed to have overlapping of two decades and fed into the reactivity calculator.

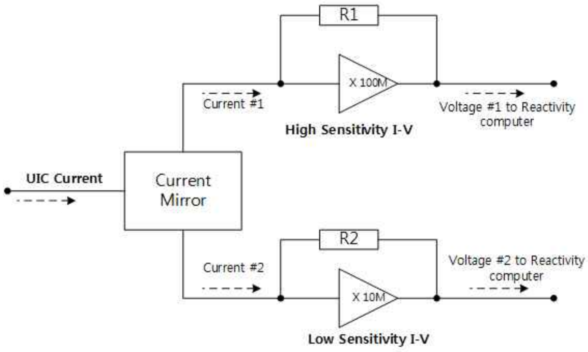

Fig. 1. Block Diagram of RCIC

Table 1. Conversion Gain for I-V Converters

	Input Current (nAmp)	Output Voltage (VDC)	Conversion Gain (mV/nAmp)
High Gain I-V	0.1 ~ 100	0.01 ~ 10	100
Low Gain I-V	1 ~ 1000	0.01 ~ 10	10

2.2 Reactivity Calculator

The reactivity calculator receives voltage signals from HGIV and LGIV for reactivity calculations. The mean value of input signals in the overlapped ranges are determined as a setpoint. Reactivities are calculated by using HGIV signals below the setpoint as well as LGIV signals above the setpoint.

As the following paragraphs Eq. 1, the reactivity can be calculated by solving the inverse point kinetics equation.

$$\rho(\Delta T) = \beta \quad \frac{\Lambda}{n(n\Delta T)} \sum_{i=6}^{6} \lambda_i C_i(n\Delta T) \quad \text{(Eq. 1)}$$

2.3 Tests in AGN-201K

Comparative tests between traditional method with Digital Reactivity Computer System(DRCS) and new method with RCIC were conducted at the AGN-201K reactor. Test parameters are compared and evaluated as for linearity and noise robustness at low current level. In Addition, the overlapping of HGIV and LGIV of the RCIC was confirmed. In order to carry out tests, UIC detectors #1 and #2 are installed at a detector hall of the AGN-201K. The signal cables of UIC #1 is then connected to the RCIC and also are connected to the reactivity computer. The signal cable the UIC #2 is directly connected to DRCS. It is noted that the DRCS at AGN-201K reactor is as the same model as the DRCS used in Korean PWRs.

2.4 Result of Linearity & Noise Robustness Test

The Power level of the AGN-201K was reduced from 60 mW to 0.06 mW by reducing reactivity to -50 pcm during tests. By varying reactor power level, reactivities were calculated based on the signals in the range of about 10 nAmp to 0.01 nAmp. And then reactivities for RCIC and DRCS were compared in terms of linearity and noise robustness.

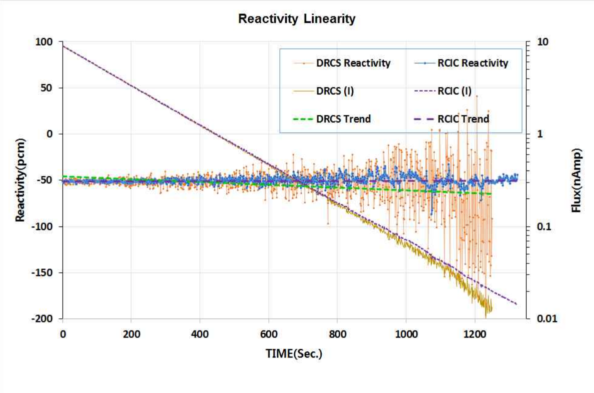

Fig. 2. Comparison of reactivity linearity for DRCS and RCIC

As can be seen in the Fig. 2, DRCS reactivity has trend to be reduced near 0.04 nAmp. On the other hand, RCIC reactivity is maintained at constant up to 0.015 nAmp and shows better linearity compared to DRCS reactivity. And also, RCIC reactivity shows very little perturbations compared to DRCS reactivity. As given in the Table 2, the standard deviation was reduced as a factor of 5 and the maximum deviation was reduced as a factor of 5 for positive reactivity region and a factor of 6 for negative reactivity region.

Table 2. Comparison of RCIC and DRCS Reactivity

	RCIC Reactivity	DRCS Reactivity
Standard Deviation (pcm)	4.269876177	23.102691
Max Deviation (pcm)	+17.3785211 -35.9874788	+96.360611 -229.977388

2.5 Result of Overlap Test

During LPPTs, the current signals from UIC detectors of control channel continuously changes from about 500 nAmp to about 0.3 nAmp. However, because input current signal of HGIC is limited to 100 nAmp. Therefore, the LGIC output signal should be used for signals of UIC above 100 nAmp. In order to use two output voltage signals continuously, it is necessary to have overlapping region representing the same reactivity. As shown in Fig. 3 and 4, RCIC reactivity is appropriate for overlapping region of three decades from 0.05 nAmp to 100 nAmp as for reactivity calculations.

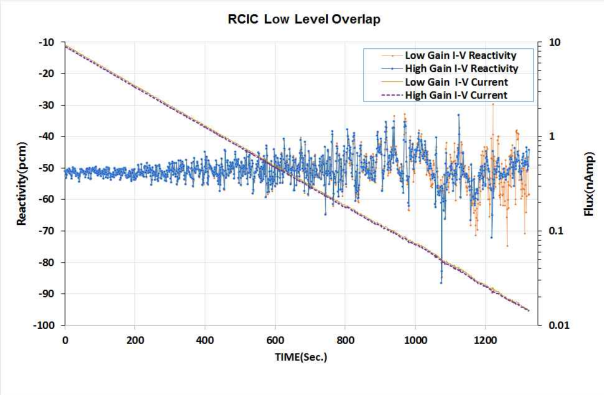

Fig. 3. RCIC low level overlap test

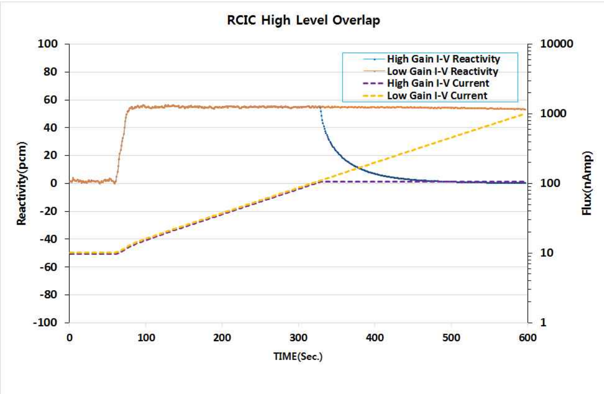

Fig. 4. RCIC High level overlap test

3. Conclusions

The UIC detector cables of the ENFMS control channel are directly connected to reactivity computer for LPPTs. Such a method could give damage to the reactivity computer and produce perturbation on reactivity due to characteristics of current meter of reactivity computer. The RCIC can resolves these problems because the RCIC has an important buffer function between the UIC and the reactivity computer. The RCIC developed in this study was tested at the AGN-201K for verification of linearity, noise robustness and overlap for the use of the RCIC in the control channel of the ENFMS. The test results show that the RCIC reactivity is much better than that of the DRCR reactivity in terms of linearity and noise robustness. When the RCIC is applied to the control channel, it can provide more accurate neutron signals to the reactivity calculator.

REFERENCES

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[2] "reload startup physics tests for pressurized water reactors" ANSI/ANS-19.6.1-2011