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On-line Inverse Count Rate Ratio Measurement System during Core Reload

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1. Introduction

All PWR plants during core loading have monitored the instantaneous neutron count rate and the ICRR (Inverse Count Rate Ratio or 1/M) to avoid an inadvertent and unexpected approach to criticality, to provide an alarm to which the operator can respond, and to terminate the event. The conventional method for monitoring the subcriticality during refueling measures the neutron count rate from source range nuclear instrumentation channels by the counter/timer, calculates ICRR and plots 1/M versus the number of the loaded fuel assemblies manually and discontinuously. It takes about 5 minutes to obtain a 1/M plot at every step after loading one assembly into core. For saving the critical path time during core reload a new online ICRR measurement system(ONICE) has been developed with good statistical properties.

2. Methods and Results

ONICE is to monitor the Inverse Count Rate Ratio (ICRR) and to verify that the next fuel assembly can be loaded into reactor without approaching criticality during reactor core loading.

ONICE measures the neutron pulse signals generated from the extraneous neutron sources in the core, which consist of the implanted primary or secondary neutron source and the spontaneous fission source due to certain isotopes that are generated in the process of fuel burn-up. The digital signal from source range nuclear instrument channel is connected to ONICE through the high speed digitizer.

Since the neutron flux count rate is a statically varying signal at low count rates, this paper describes a kernel regression based noise smoother

Kernel regression[1,2] is the estimation of the functional relationship $y(t)$ between two variables y and t. Measurement produces a set of random variables $\{t_i, y_i; i = 1,\dots,N\}$ on the interval $\{0 \le t_i \le T\}$. It is assumed that

$$y_i = y(t_i) + \varepsilon \tag{1}$$

where ε is a random noise variable with the mean equal to zero. The Nadaraya-Watson kernel regression estimate $y(t)$ of at $t = \tau$ from this random data is defined as the estimator $\hat{y}(\tau)$ as

$$\hat{y}(\tau) = \frac{\sum_{i=1}^{N} y_i k(\tau - t_i)}{\sum_{i=1}^{N} k(\tau - t_i)} \tag{2}$$

The function $k(\tau - t_i)$ is the kernel function which can be chosen from a wide variety of symmetric functions. In this paper, the Gaussian density function is used, i.e.,

$$k(t) = \exp(-D(t_i, t_q)^2 / \sigma^2) \quad (3)$$

where D is the distance metric and Euclidean distance is used here defined by

$$D(t_i, t_q) = \|t_i - t_q\| = \sqrt{(t_i - t_q)^2}\ . \quad (4)$$

t_q is the query point where the smoothed signal is to be generated in the interval of time series data $\{0 \le t_i \le T\}$. σ^2 is the bandwidth of the kernel. σ^2 is a scaling factor which controls how wide the influencing measurements are spread around a query point.

Using the filtered digital pulse counts, ONICE can calculate ICRR (1/M=Co/Ci) and plot 1/M versus the number of the loaded fuel assemblies after an assembly is loaded into the reactor. If the neutron count rate increases by a factor of five from the last counts stable value, ONICE provided an alarm which the operator can immediately withdraw the last inserted fuel assembly and terminate the event. Also, ONICE can transfer the neutron count rate and ICRR to the containment vault through the communication protocol.

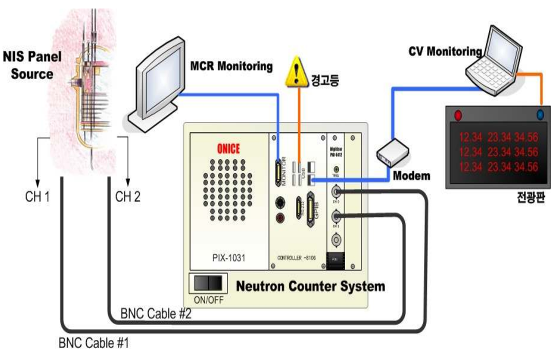

Fig. 1. Structure of ONICE System

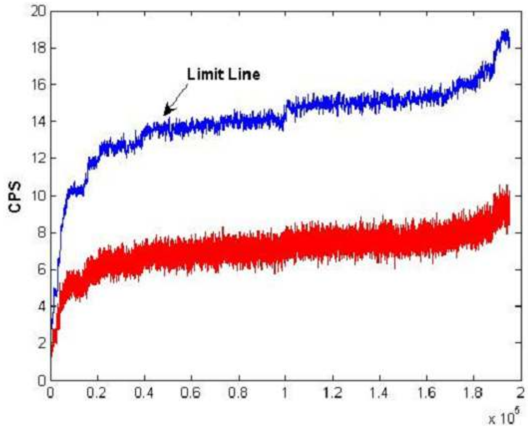

Fig. 2. Neutron count rates during core reloading.

3. Conclusions

The ONICE package was practically used and tested during core refueling in YG3 and UJ 4. Also, it has particular application to the detection of inadvertent boron dilution in a shutdown PWR. The program is ready for use also in other CANDU type NPPs. ONICE system can reduce the refueling time and increase the capacity of nuclear plants. Also the continuos monitoring of the subcriticality and the function of pre-alarm are expected to enhance the safety of nuclear power plants during core reloading.

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