Digital Power Range Neutron Monitoring System

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Abstract: PRNM(Power Range Neutron Monitoring) of BWR (Boiling Water Reactor) is a system that processes signals from about two hundred LPRM (Local Power Range Monitor) sensors in the nuclear reactor and this system monitors the neutron flux level during the plant operating region.

Development has been made by employing a special technique for multiplexing neutron sensor signals and the recent advanced micro-electronics technology.

It is applicable to the total plant digital control system for a nuclear power plant.

1 Introduction

PRNM of BWR is one of the most important nuclear reactor monitoring systems, which deals with a lot of in-core neutron sensor signals and reactor core flow signals, and classified to one of nuclear safety systems(class 1E) that relate to the nuclear plant scram.

Toshiba has developed a series of digital nuclear control and instrumentation systems under Advanced Control and instrumentation Concept(ACC) for Advanced BWR nuclear power plant(Fig.1).

Several systems such as a digital area-process radiation monitoring system and a digital Traversing-Incore-Probe(TIP) monitoring system have been already applied to recent nuclear power plants.

Based on the previous activity [1)-5)], the class 1E digital nuclear instrumentation system has been developed to meet the nuclear safety and system requirements.

By this development, a series of nuclear instrumentation systems has completed as shown in Fig.2.

Digital PRNM(DPRNM) system aims to improve conventional analog system in several points such as reduction of transmission lines, self-diagnosis functions, centralized monitoring function through an advanced electro luminescence display panel and modular structure of electric boards for easy inspection and maintenance.

Those improved features of the newly developed PRNM including digital Rod Block Monitor(DRBM) are described in this paper.

2 System outline of DPRNM

DPRNM should monitor the neutron flux level during the plant operating region of BWR.

A LPRM sensor signal is small(several uA to mA) on HV line. Conventional PRNM system performed the analog signal processing in the control room.

The developed system has distributed-local-units that convert the analog signal to digital data directly by HV current multiplexer and signal processor. It is featured by the use of optical data links between the control room and the distributed-local-units to reduce many LPRM signal cables that transmit small signals for a long distance. A drastic reduction of signal transmission cables has been performed through the realization of distributed-local-units.

As PRNM is classified to a nuclear safety system(class 1E), the system is divided into 4 or 6 independant divisions. Each sub-system is a redundant system, and the class 1E units and non-class 1E units are electrically and physically separated by fiber and physical shields to meet the nuclear safety requirements.

A standard divisional DPRNM system configuration is shown in Fig.3.

Local units that multiplex the LPRM signals are installed in the reactor building near the reactor.

APRM unit is a functional center of DPRNM based on micro-processor technology. This unit receives digitalized and multiplexed signals, checks each LPRM level signal and calculates APRM level value and monitors reactor power.

This APRM unit has functions such as gain calibration of LPRMs and APRMs caused by neutron irradiation and additional tests for the diagnosis of sensors and electronics besides the normal monitoring functions.

3. Design and Features of DPRNM

Main components of the DPRNM are described here and their features are clarified.

3-1 Distributed-local-unit

This is one of the most important parts for the realization of safety grade system.

In order to develop a reliable and compact signal multiplexing, several methods have been investigated.

Basically the current signals from the LPRM sensors are processed through a current to voltage converter so that there are two alternatives as a multiplex position.

One is multiplexing on the HV line of the sensors and the other is on the current to voltage converter's output.

In the later case, the volume reduction effect is not great because of necessary cables and hardware.

On the other hand, if the multiplexing is done on the HV line without any special care, the difficulty of the fast and stable multiplexing of HV lines should cause the degradation of the reliability of multiplexed signals.

Design approach for this is shown in Fig.3.

Here a new technique has been developed to resolve the problem of a fast and reliable multiplexing of the small current on HV line and it has been applied as shown in Fig.4.

Now suppose that the biased voltage of the neutron sensor is (E1+E2), where E2 is about 0.5 volt and E1 is 99.5 volt, for example.

The current to voltage converter is biased by the tension of the sum of E1 and E2 and a selected neutron sensor is also biased by the same voltage (E1+ E2).

Since the all other neutron sensors non-selected are continuously biased by the power supply of the voltage E1, diodes connected to those neutron sensors' HV lines are all forward biased. Therefore, all non-selected neutron sensors work normally under the E1 volt bias but the currents of those sensors do not flow into the current to voltage converter.

It is important that a diode connected to a selected neutron detector is reversely biased so that the current from the selected neutron sensor does not flow through the diode but flows into the current to voltage converter.

Since the difference between the bias voltage for the selected neutron sensor and that of the non-selected ones is so small like 0.5 volt that the switching from the selected neutron sensor to the non-selected one or the vice versa is very easy and fast enough for the safety grade operation of DPRNM.

Multiplexed analog signals in a time domain are transfered to an analog to digital converter and translated to bit serial signal for the optical transmission.

In addition to the fundamental hardware for the multiplexing, this unit has other electronic components such as sensor bypass switches, calibration resistors and calibration switches, voltage regulated power supply for the current versus voltage characteristics of LPRM as well as the fixed voltage power supplies. The hardware is controlled through fiber optic transmission line by the APRM main processing unit in the control room.

3-2 APRM Unit

APRM unit is designed according to the standard design of the nuclear instrumentation systems under ACC.

This unit has microprocessor based structure and should function as the control center of DPRNM total system. Fig.5 shows the figure of the APRM unit and Fig.6 shows the card configuration of the APRM unit. Optic communication cards No.1 to 4 receive the digitalized and multiplexed sensor signals and transmits the control commands to local units asynchronously.

The function of the APRM units is performed by three control processing unit(CPU) cards such as a main cpu card, a display cpu card and a diagnosis cpu card.

The main cpu card performs primary function such as the level calculation of LPRM, APRM and flow signals, the determination of the reactor trip and rod block output, control of the local units and the on-line gain calibration.

DI and DO cards have the electrically isolated inputs and outputs.

The display cpu card controls the display with the devices installed at the front pannel via display card.

Self diagnosis capability is provided in each cpu card in conjunction with the history of trip outputs, rod block outputs, alarm announciation and operations done by operators. Based on the logged information, the diagnosis cpu card identifies failed cards or components so that the repair should be done quickly.

3-3 I/O Unit

I/O functions are summarized in Fig.7. The I/O unit has two cpu cards for the fast processing of I/O functions. The main cpu card is a primary function controller of the I/O unit and controls the I/O devices via the optic communication cards, the digital output card, and the analog input cards. The communication cpu card is a slave controller of the communication card which has serial and parallel communication capability. The communication cpu is linked with the main cpu via two port RAMs.

3-4 RBM Unit

By the optic communication line of APRM unit, the calculated LPRM data is transmitted to Rod Block Monitor(RBM). RBM unit should monitor the neutron flux level of selected control rod.

The developed RBM has the extended function be able to monitor all LPRM information to meet the future need for rod gang scan.

Improved Man-Machine interface and standardized hardware configuration are same as APRM unit.

Fig.8 and Fig.9 shows the card configuration and an electro luminescence display of RBM unit.

3-5 Operator-Machine Interface Function

3-5-1 Information Display

The improved Man-Machine interface is realized

by an electro luminescence display and programmable function keys.
Fig.10 shows a hierachical structure of display screens of the APRM unit.
Through these screens, operators can monitor the output of the DPRNM and control it easily.
The monitoring and control functions realized by the DPRNM operator-machine interface are summarized as follows.

1) Display of APRM, LPRM and flow levels with related information such as alarm annunciation and trip output.

2) Display of the system parameters such as sensor identification numbers and setpoints for trip and alarm output.

3) Display of the operation mode of the DPRNM.

4) Control of the operation mode of the DPRNM.

5) Control of the on-line gain calibration and the automatic current versus voltage characteristics measurement of neutron sensors.

6) Change of the system parameters.

Display of APRM is shown in Fig.11.

3-5-2 Gain Calibration through Operator-Machine Interface

The on-line calibration of APRM and LPRM gains is performed easily through the front panel of APRM unit. The procedure begins with the request of downloading of gain values from the process computer. This request is made by pushing one of the programmable function keys at the front panel and transmitted to the process computer via the I/O unit. When the gain values are downloaded from the process computer to the APRM unit, they are stored in RAMs in the APRM unit and displayed at the electro luminescence display for the confirmation. If the gain values transmitted from the process computer are correct, the old values which are stored in EEPROMs in the APRM unit are updated with the new ones by the permission of the operator. The updated gain values are then displayed for the confirmation and permission again. And with the second permission by the operator, the APRM unit begins to use the updated gains. This gain calibration procedure requires the divisional bypass of the APRM unit.

3-5-3 Sensor Current Versus Voltage Characteristics measurement

The automatic measurement of LPRM sensor's plateau characteristics is performed by the operation of the programmable function keys. There are no necessity of additional equipments nor the reconnection of LPRM sensor's cables.
The bias voltage can be automatically changed in the range of 0 volt to 250 volts DC. The results are transmitted to the maintenance unit via the I/O unit and displayed on the electro luminescence display.

3-5-4 Diagnosis Capability

The system diagnosis functions are so carefully selected that the failed card can be repaired in less than eight hours even of the local unit failed.

4 System Performance Verification

The functional tests have been performed under the environment shown in Fig.12. A flux simulator provides the simulated current signals to the local unit. As expected, the multiplexing speed of 50 micro-seconds per a LPRM sensor has been obtained with the linearity which meets the requirements for the conventional PRNM.

5 Summary

The newly developed Digital Power Range Neutron Monitoring System has new advanced features as safety grade systems such as direct multiplexing of LPRM sensors, optic transmission, fully digitalized signal processing, improved man-machine interface, on-line calibration of APRM and LPRM gains, automatic plateau characteristic measurement, self-diagnosis capability and RBM flexbility to extend the system function such as rod gang scan.
With these features, the DPRNM should contribute to the improvement of plant operability, maintenability, reliability and the reduction of cables and components under the Advanced Control Concept established by Toshiba.

Reference

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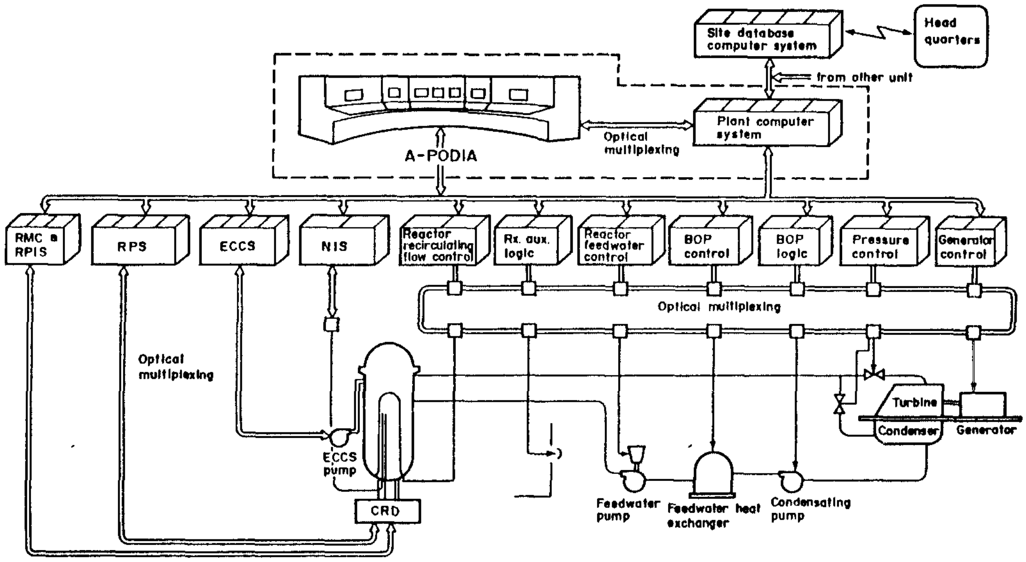

Fig.1 Digital Integrated C&I System

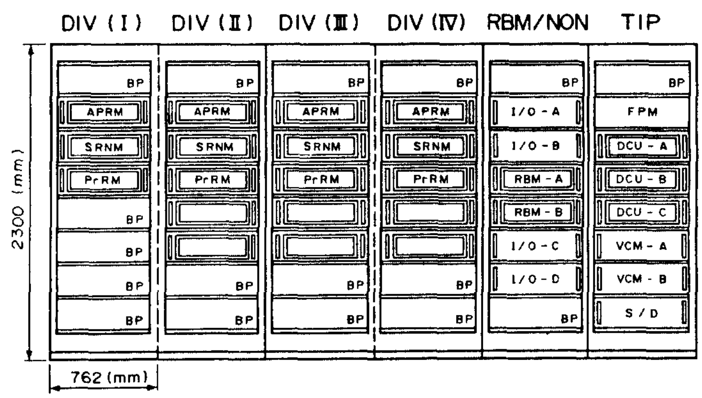

Fig.2 Nuclear Instrumentation System Panel Configuration

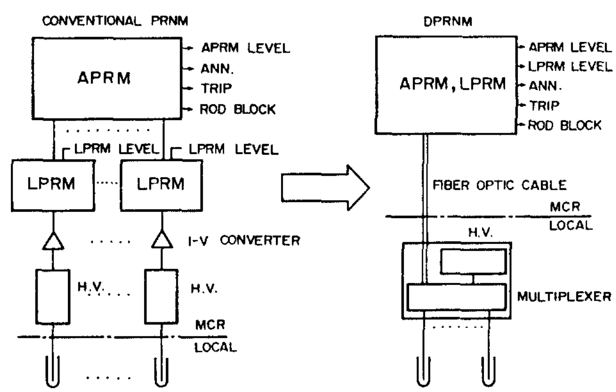

Fig.3 Design Approach of DPRNM System Configuration

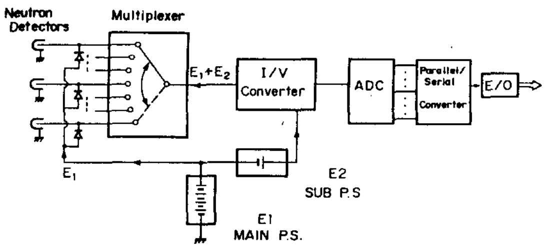

Fig.4 Principle of Signal Multiplexing

Fig.5 Figure of APRM Unit

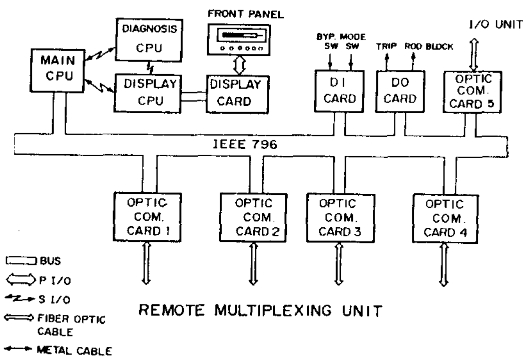

Fig.6 Configuration of APRM Unit

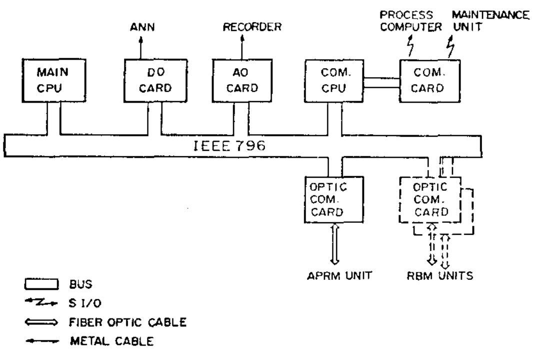

Fig.7 Configuration of I/O Unit

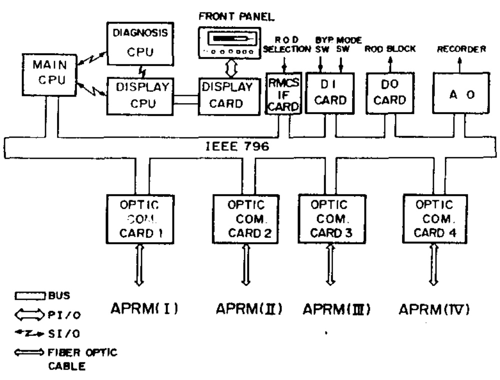

Fig.8 Configuration of RBM Unit

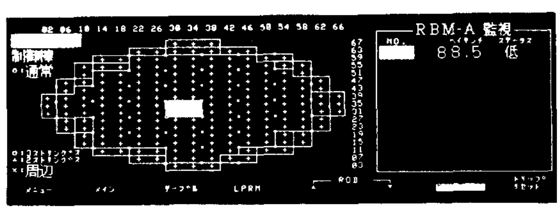

Fig.9 RBM Display

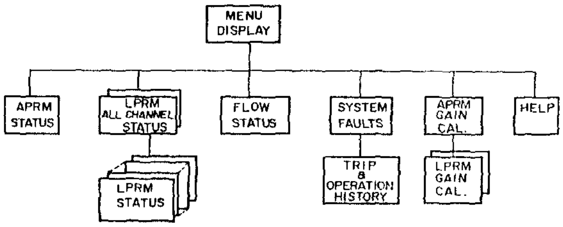

Fig.10 APRM Display Menu

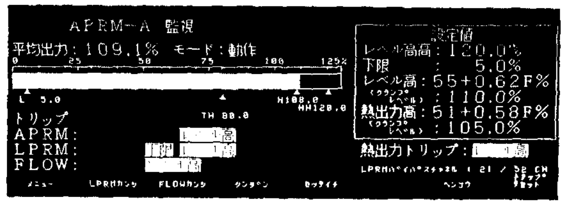

Fig.11 APRM Display

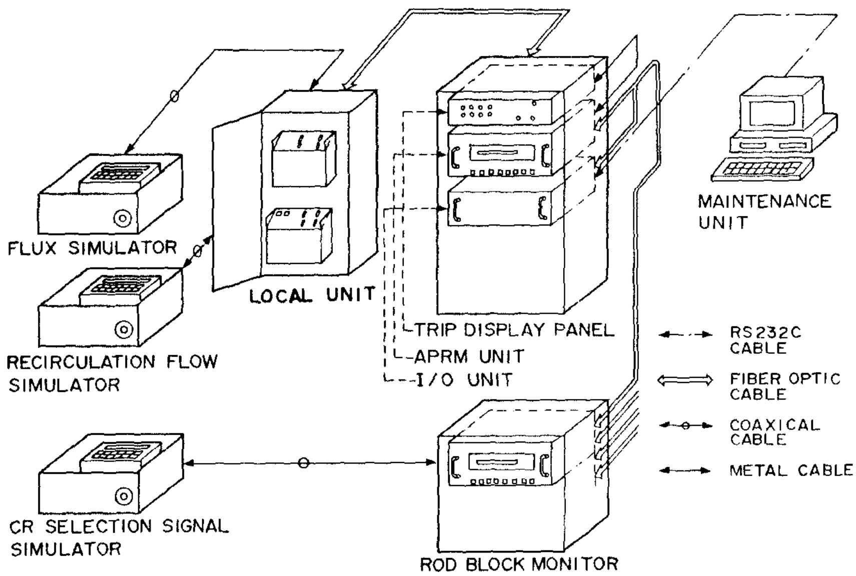

Fig.12 Functional Verification