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New Measuring and Protection System at VR-1 Training Reactor

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ABSTRACT

The contribution describes the new measuring and protection system of the VR-1 training reactor. The measuring and protection system upgrade is an integral part of the reactor I&C upgrade. The new measuring and protection system of the VR-1 reactor consists of the operational power measuring and the independent power protection systems. Both systems measure the reactor power and power rate, initiate safety action if safety limits are exceeded and send data (power, power rate, status, etc.) to the reactor control system. The operational power measuring system is a full power range system that receives signal from a fission chamber. The signal is evaluated according to the reactor power either in the pulse or current mode. The current mode utilizes the DC current and Campbell techniques. The new independent power protection system operates in the two highest reactor power decades. It receives signals from a boron chamber and evaluates it in the pulse mode. Both systems are computer based. The operational power measuring and independent power protection systems are diverse - different types and location of chambers, completely different hardware, software algorithms for the power and power rate calculations, software development tools and teems for the software manufacturing.

1 INTRODUCTION

The VR-1 reactor is a pool-type light-water reactor based on enriched uranium (under 20%). Its thermal power is rated up to 5kW. The reactor is utilized primarily for training university students and future nuclear power plant staff. The training at the VR-1 reactor is oriented to the reactor and neutron physics, dosimetry, nuclear safety, and control of nuclear installations.

The VR-1 training reactor has been operated since 1990 by the Department of Nuclear Reactors, at the Faculty of Nuclear Sciences and Physical Engineering of the Czech Technical University in Prague. The reactor was designed and built by the Škoda Company in co-operation with the Faculty. The reactor control and safety system (I&C) was developed in the mid- 80s. The system is digital. Even though the present control and safety system fully covers the demands that are put on it, its technical design is obsolete to a certain extent at the present time. Therefore, it was decided to upgrade the present control and safety system with the aim to apply the latest available techniques and technology observing the relevant guides, recommendations and standards.

The principal upgrade of the control and safety system started in 2001. Because of the frequent utilization of the VR-1 training reactor during the academic terms, it was decided to carry out the upgrade gradually – in stages during holidays so as not to affect the training at the reactor. The first stage was the human-machine interface and the control room upgrade in 2001. During the second stage of the upgrade in 2002, the control rod drives and the safety circuits were replaced. The third stage – the control system upgrade – was carried out in 2003.

The next upgrade stage is the safety (protection) system upgrade consisting of independent power protection and operational power measuring systems upgrade. The new independent power protection system was developed in 2004, licensed and installed in 2005. The last stage is the operational power measuring system upgrade; the system is developing now and is going to be installed in 2007.

2 CONTROL AND SAFETY SYSTEM STRUCTURE

This chapter explains the position and function of the operational power measuring and the independent power protection systems in the complete reactor control and safety system (I&C). A block diagram of the control and safety system is shown in Figure 1. The system structure has to meet the requirements of the Czech State Office for Nuclear Safety [1].

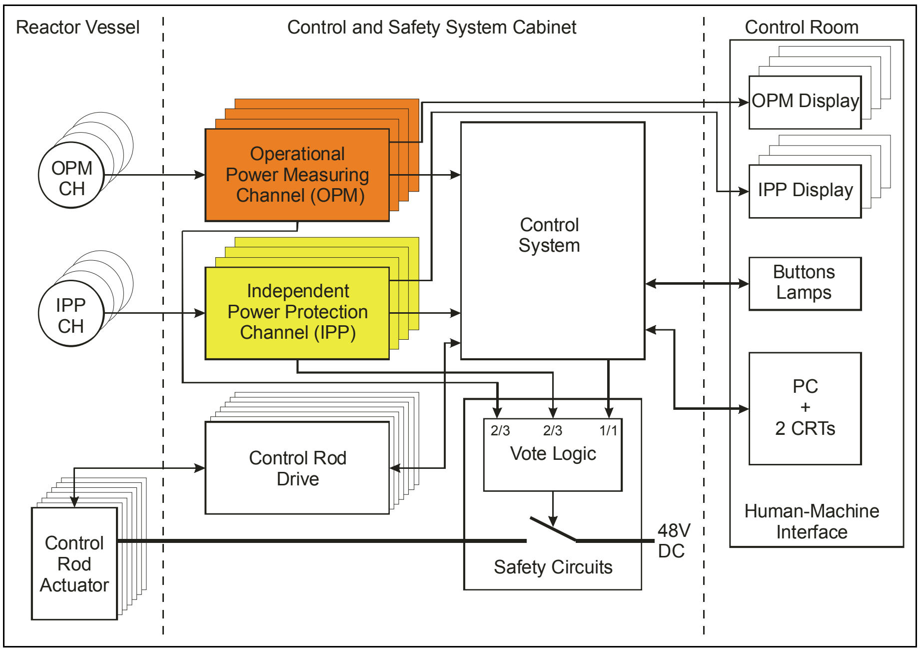

Figure. 1: Block diagram of the upgraded control and safety system

2.1 Description of System Structure

Firstly, the safety (protection) part of the system is described. This part of the I&C is the most important one for nuclear safety. The four operational power measuring channels (OPM, orange in Fig. 1) receive signals from wide range fission chambers (OPMCH), evaluate them, calculate the reactor power and the power rate, and send the values to the control system and to adjacent individual displays on the operator's desk of the human-machine interface (HMI) in the control room. Four channels equipped with boron chambers (IPPCH) work as an independent power protection system (IPP, yellow in Fig 1.). They also evaluate the power and the power rate, send data to the control system and to their displays and initiate a safety action if safety limits are exceeded.

The control system receives data from the OPM and IPP channels, checks received values with each other and against the safety limits. The control system calculates the average values of the reactor power and the power rate; next, it evaluates the deviation between the real power and the demanded power value set by the operator. The control system sends data to the HMI and receives commands from it. If the commands are permitted, it carries them out. The control system also serves as an automatic power regulator system and controls the movement of the control rods to achieve the required reactor power. The control rod movement is actuated by control rod drivers.

The HMI enables the communication between the control and safety system and the operator. It consists of a computer with CRT displays and indicators to show the operational status of the reactor, as well as a keyboard and buttons to control the reactor. The HMI also stores data about the history of the reactor operation.

2.2 Safety (Protection) Features of the System

Defense in depth, redundancy and diversity are applied in the reactor control and safety system to enhance its safety and reliability. Under standard conditions, the control system operates the reactor (the first level of the defense in depth), monitors the safe operation of the reactor, and if necessary, it stops the chain reaction in the reactor (reactor scram). If any problems appear within the control system, the protection system (the second level of the defense in depth) consisting of the OPM and IPP channels independently checks the reactor status; if the safety limits are exceeded, it stops the chain reaction.

To fulfill the single failure criterion, the protection system utilizes redundancy. There are four OPM and four IPP channels, three of them are active, the fourth ones operate in the stand-by mode. The channels are fully independent so that consequences of a single failure in any channel cannot penetrate to the other ones. Safety signals from both OPM and IPP channels are evaluated in the logic 2 out of 3. To protect against the common mode failure, the protection system applies diversity. There are diverse OPM and IPP channels. They vary in sensors (fission and boron chambers), hardware, and software.

The control system evaluates the reactor power, the power rate, the deviation in data of single OPM channels, system and technology status. If any failure appears, it sends the safety signal to initiate the reactor scram. The OPM and IPP channels independently compare the reactor power and the power rate with the safety limits; if these limits are exceeded, or any internal error appears, they send safety signals.

A vote logic receives the safety signals. The vote logic evaluates the inputs from the OPM channels in the logic 2 out of 3, from the IPP channels independently 2 out of 3, and the safety signal from the control system is evaluated in the logic 1 out of 1. If the conditions for the safety action request are met in at least one group (OPM, IPP or Control System), the power supply (48V DC) to the control rods is broken by the safety circuits, the rods fall down and stop the chain reaction (reactor scram). Because of the low power of the VR-1 training reactor, it is not necessary to remove residual heat from the active core.

3 NEW INDEPENDENT POWER PROTECTION SYSTEM

The development of the new independent power protection (IPP) channel started in 2004. The general contractor of the project was Škoda Nuclear Machinery Company Plzeň, and the hardware and software subcontractor was Tedia Limited. The Department of Nuclear Reactor prepared the general, hardware and software requirement, software quality assurance, verification & validation and configuration management plans, developed the safety software and carried out verification & validation. The Department has also taken an active part in the system tests.

The detailed hardware and software description of the new IPP channel contains literature [2]. This article is focused on the validation of the new IPP channel carried out at the Department.

3.1 IPP Channel Validation

The IPP validation tests finalized the IPP channel development. The first validation tests were accomplished non-active with simulated input signals instead of neutron chambers. After the successful non-active tests, the IPP channel was examined in the normal reactor operation.

The non-active validation tests were carried out by VXI and HPIB instruments controlled by PCs. The block diagram of the IPP validation system is shown in Figure 2. The arbitrary signal generator HPE1441A in a VXI rack provides pulses to simulate neutron flux (reactor power). The PC controls the VXI devices via a FireWire line. The pulse signal is modified by a simple electronic circuit to get small pulses comparable with the neutron chamber signal. The second PC (PC-NB) receives messages and sends commands (e.g. operational mode changes, setting of stricter safety and warning limits) from/to the IPP channel, and controls via the HPIB interface the HP34401A multimeter that monitors the safety relay status.

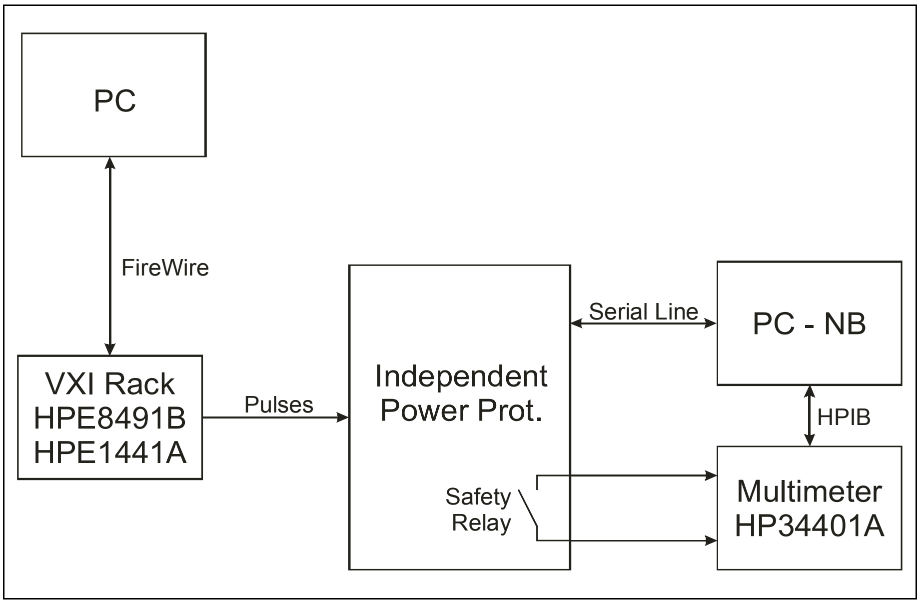

Figure 2: Block diagram of IPP validation tests

The software for validation test was prepared in the Agilent VEE development tool. Three programs were developed; the first one for generation of the simulated reactor power course, the second one for the pulse generator control and the third one for the communication with the IPP channel, the safety relay monitoring and the IPP channel status evaluation and control. Different reactor power courses were prepared for the validation tests – linear and step increase of the reactor power, linear and step increase of the power rate, quick and slow changes of the reactor power and the power rate. The IPP tests of the power and power rate measurement, the power and the power rate scrams were carried out for both standard and stricter warning and safety limits. The test with the step increase of reactor power is shown in Fig. 3 (yellow – 'row' neutron flux (power) from the chamber, blue – calculated power by the IPP channel, violet – calculated power rate, red – safety relay status). The figure presents the safety action initiation because of the power exceeding.

After the successful simulation (non-active) tests, the IPP channel was tested active during the normal reactor operation. The safety functions of the channel were first tested with standard and then stricter safety limits. Finally, the IPP system was licensed by the Czech State Office for Nuclear Safety after detailed examination and installed into the VR-1 reactor I&C during the summer 2005.

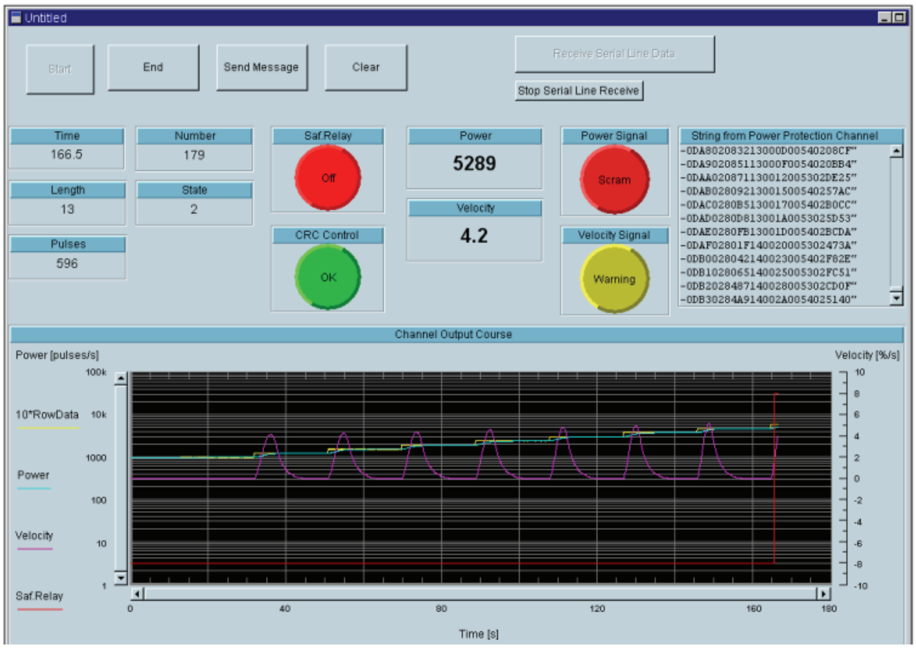

Figure 3: Validation test with step increase of power

4 NEW OPERATIONAL POWER MEASURING SYSTEM

The Operational Power Measuring (OPM) system of the VR-1 training reactor at Czech Technical University in Prague is a part of the reactor safety (protection) system (see chapter 2). The OPM channels receive signal from the wide range fission chambers RJ1300, evaluate it according to the reactor power in pulse or current range, calculate the reactor power and the power rate, and send the values to the reactor control system and to the adjacent individual display on the operator's desk of the HMI in the reactor control room. The channels also compare values of the power and the power rate with the safety limits, and if the limits are exceeded, the request for a safety action is sent to the vote logic. Next, the OPM channels send the calculated reactor power and power rate together with the system status, etc. to the control system.

The general contractor of the operational power measuring system upgrade is Škoda Nuclear Machinery Pilsen, the subcontracts are Tedia Pilsen and dataPartner České Budějovice. The Department of Nuclear Reactors prepared the OPM system requirements [3], provides experience with the neutron flux measurement and is going to co-operate during the verification & validation and the system licensing process.

4.1 OPM Channel Requirements

The OPM channel requirements [3] were prepared by the Department of Nuclear reactors. The requirements consist of general, hardware and software requirements. The following list provides a summary of the OPM channel basic requirements divided into the operational and safety requirements.

4.1.1 OPM Channel Operational Requirements

- evaluation of reactor power according to the pulse, current or Campbell data from the OPM channel analog section (used data range depends on the actual reactor power) with respect to data fluctuations, etc.
- evaluation of the power rate according to the pulse, current or Campbell data from the OPM channel analog section (used data range depends on the actual reactor power)
- sending the reactor power, the power rate, the status, etc. to the control system and the HMI individual display
- receipt and execution of commands from the control computer (safety limits changes – only stronger values than default, operational modes changes, etc.)
- OPM channel operational modes control:
  - measuring – analog data evaluation, the power and power rate calculations, safety and warning signals evaluation; safety relay control according to the safety signals evaluation
  - reserve - analog data evaluation, the power and power rate calculations, safety and warning signals evaluation; safety relay switched off
  - test - automatic or manual testing with simulated signals, hardware checks, memory checks, adjustable values checks, etc.; safety relay switched off
- communication with the control system - fiber optics duplex serial communication, data messages integrity checks (e.g. CRC), communication from the control system must not negatively influence the OPM channel (functional isolation)
- communications to the individual display - fiber optics simplex serial communication

4.1.2 OPM Channel Safety Requirements

- comparison of the calculated reactor power with warning and protection limits, evaluation of warning and safety signals, in the ‘measuring’ mode proper safety relay control else safety relay off
- comparison of the calculated power rate with warning and protection limits, evaluation of warning and safety signals, in the ‘measuring’ mode proper safety relay control else safety relay off
- system consistency and integrity checks, memory contents checks, adjustable values (high voltage, discrimination level, etc.) checks, watch-dog, etc; if any problem occurs then protection signal and safety relay switch off

4.2 OPM Channel Hardware

The operational power protection channel consists of an analog and a digital section. The analog section processes the chamber signal and transforms it to be suitable for the digital section.

4.2.1 Analog Section

The analog section processes the neutron chamber signal either in pulse, Campbell [4] or DC current ranges and provides signals proportional to the neutron flux density (reactor power). The block diagram of the analog section is in the Fig. 4.

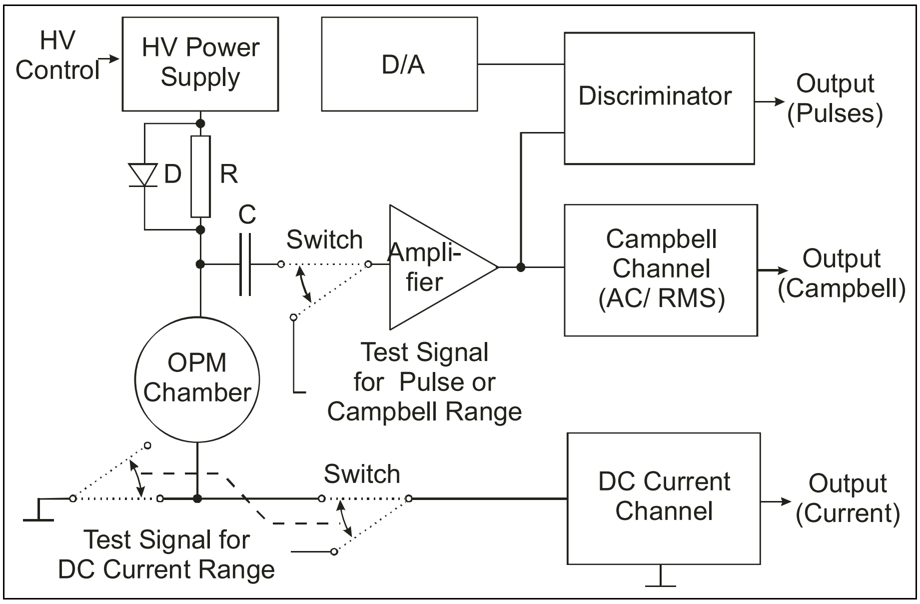

Fig. 4: Block scheme of the OPM channel analog section

4.2.2 Digital Section

The digital section of the OPM channel is based on a high quality industrial PC with an appropriate additional hardware – an input unit for reading data from analog section; a supervisory unit for the supervision of the OPM hardware and software; communication unit for communication with the control system, the control desk individual display and service computer; local display for the OPM status presentation and a safety relay to control the safety circuits. The block diagram of the OPM channel digital section is in the Fig. 5.

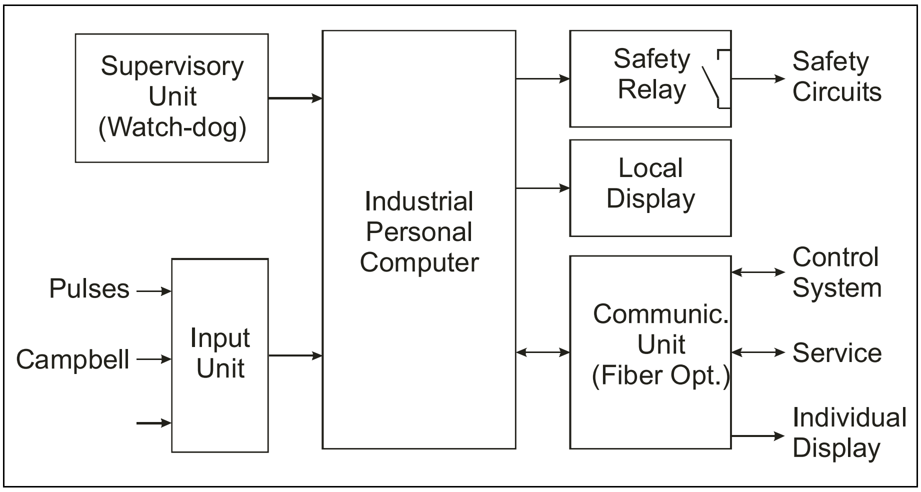

Fig. 5: Block scheme of the OPM channel digital section

4.3 OPM Channel Software Quality Assurance

The OPM channel software has to fulfill quality requirements for the safety (protection) systems of nuclear facilities; quality assurance, configuration management, verification and validation activities must fulfill respected standards and guides [5]. The computer operating system is going to be the reputable system Phar Lap, the software is going to be coded in the C Language with respect to [6]. Corresponding software life cycle documentation has to be delivered together with the software.

The Department of Nuclear Reactors is going to take an active part during the verification & validation phase of the software life cycle. The Department plans to carry out validation test with the HPIB and VXI pulse and current generators controlled by software developed utilizing the Agilent VEE development tool.

5 CONCLUSION

The contribution describes the new measuring and protection system of the VR-1 reactor that consists of the IPP and OPM systems. The protection and measuring system upgrade is an integral part of the whole VR-1 reactor I&C upgrades that started in 2001. The IPP system was developed in 2004, tested, licensed and installed in the summer 2005. The OPM system development started in the spring 2006, the channel prototype for testing is going to be available in the autumn 2006. The licensing and installation of the OPM system is planned during the summer 2007.

Both OPM and IPP systems provide in comparison to the previous systems better neutron chamber signal processing, the OPM channels utilize newly the Campbell technique to ensure the gamma discrimination in the current mode range of the chamber. The computers of the OPM and IPP channels offer substantially higher computational performance, software prepared in a high level programming language (the C language), fulfillment of the quality assurance requirements in both hardware and software production according to the respected international guides and standards.

Reliable and safe operation is important because the training reactor VR-1 is very intensively used for training of students and future nuclear power plant staff. Every year, some 200 university students from Czech universities get acquainted with the reactor. The reactor is also used for training of students of many European universities and involved into some international programs such as the IAEA training courses (e.g. recently for Bulgarian specialists) and technical cooperation program and in the European programs ENEN and NEPTUNO for nuclear education (e.g. Eugene Wigner Training Courses) [7].

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