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RADIYTM-Based Rod Control Systems

Rod Control System (RCS) is an Instrumentation and Control system that consists of safety-related class 1E (category A functions) Rods Position Indication System (RPIS) and Rod Drives Control System[1] (RDCS) used to detect and display precise rods positions in the real-time mode, rod drives automatic and manual control and to transmit corresponding information to the Unit Data Acquisition System (Plant Information & Monitoring System) within the interconnection with the Reactor Trip (Protection) System, In-Core Monitoring System and other systems.

1.0 General Requirements for Modern Rod Control Systems

Safety

- single failure tolerance criterion;
- full redundancy of the monitoring, indication, rod drives control logic and control channels;
- physical separation (galvanic isolation) of system Inputs/Outputs (I/O);
- independence between redundant control channels; and
- easy and practical Human-System Interfaces excepting misunderstanding cases and human-factor errors.

Field Interfaces

- connection with different types of coil-based (needed power supply) and switch-based Rods positions sensors; and
- connection with different types of rod drives electrical motors (stepper or three-phases synchronous / asynchronous) with different power parameters.

Control, Monitoring and Testability

- all Unit rod drives should be controlled in the 24/7 real-time mode;
- process the emergency protection (EP) signals and rods position sensors inputs signals, validate the inputs and use validated inputs to form adequate commands in automatic mode and displaying all safety parameters (at the rods positions indication panels in the MCR and ECR) for monitoring:
  - real rods positions;
  - rod drives operability and electric motor coils status (resistance/ and temperature); and
  - falling rods status (in case of emergency trip situation).
- monitor the RCS online diagnostics status;
- transmit the safety parameters, field inputs, alarms and RCS status to the 1E Class safety and safety-related systems (Reactor Trip / Protection System (RTS / RPS), Safety Display System, Post-Accident Monitoring System (PAMS) and In-Core Monitoring System, if it's needed);
- transmit the safety parameters, field inputs, alarms and RCS status to the Non-1E system (Plant Computer, Data Acquisition and Display System, or DCS);
- process operator inputs: bypass for individual field inputs and outputs during rod drives control logic channel testing, EP acknowledgement/reset, manually rod drives control signals, etc.; and
- perform online diagnostics & tests and transmit the system status to the safety display and Non-1E system; perform one-by-one off-line rod drives testing during Unit outage and transmit the control rod drives status to the safety display system and Non-1E system.

1. In some PWR designs RDCS it's a non-safety class (Non-1E) system, which are perform categories B & C functions.

Operator Human-System Interface (HSI)

- enhanced visibility of system, rods, and rod drives parameters in real-time;
- allow the operator to set the following parameters: bypass for individual inputs and outputs signals, acknowledgement/reset for EP signals;
- easy navigation between the various operator screens;
- viewing of current and archived plant and diagnostic data;
- color encoding;
- immediate annunciation of failures detected by diagnostic system to operator by video-frames on screens and provision of situation-specific operator aids (decision aids, detailed information about equipment etc.);
- task-related display in an appropriate form for operator actions;
- presentation of situation-specific, pre-processed condensed information in an appropriate context with display formats for system status, trend curves and process diagrams;
- localization according to customer requirements (for example, in commissioned RADIYTM-based systems Bulgarian, Russian, Ukrainian and English languages were used); and
- use of homogeneous hardware.

Communications

- ability to interface with existing non-safety (Non-1E) system (plant computer, data acquisition and display system, or DCS); and
- redundant, high speed, industry standard communication interfaces and protocols to transfer real-time data (such as safety parameters, field inputs, alarms, and RCS status) for monitoring and display, logging and trending for field diagnostics purposes.

Reliability, Availability and Maintainability

- high reliability and availability (99.99%) with no single point of failure;
- online diagnostics with over 99.9% coverage;
- online repair using hot-swappable modules;
- easy to maintain, modify and add future enhancements; and
- easy to upgrade and expand in the future without affecting existing field elements and wiring.

Accuracy and Timing Properties

- measurement resolution for measurement channels, signaling channel etc. should be not less than 0.1% from measurement range; and
- summary operational cycle for Rods positions monitoring and Rod Drives command signals forming processes should be less than 20 ms.

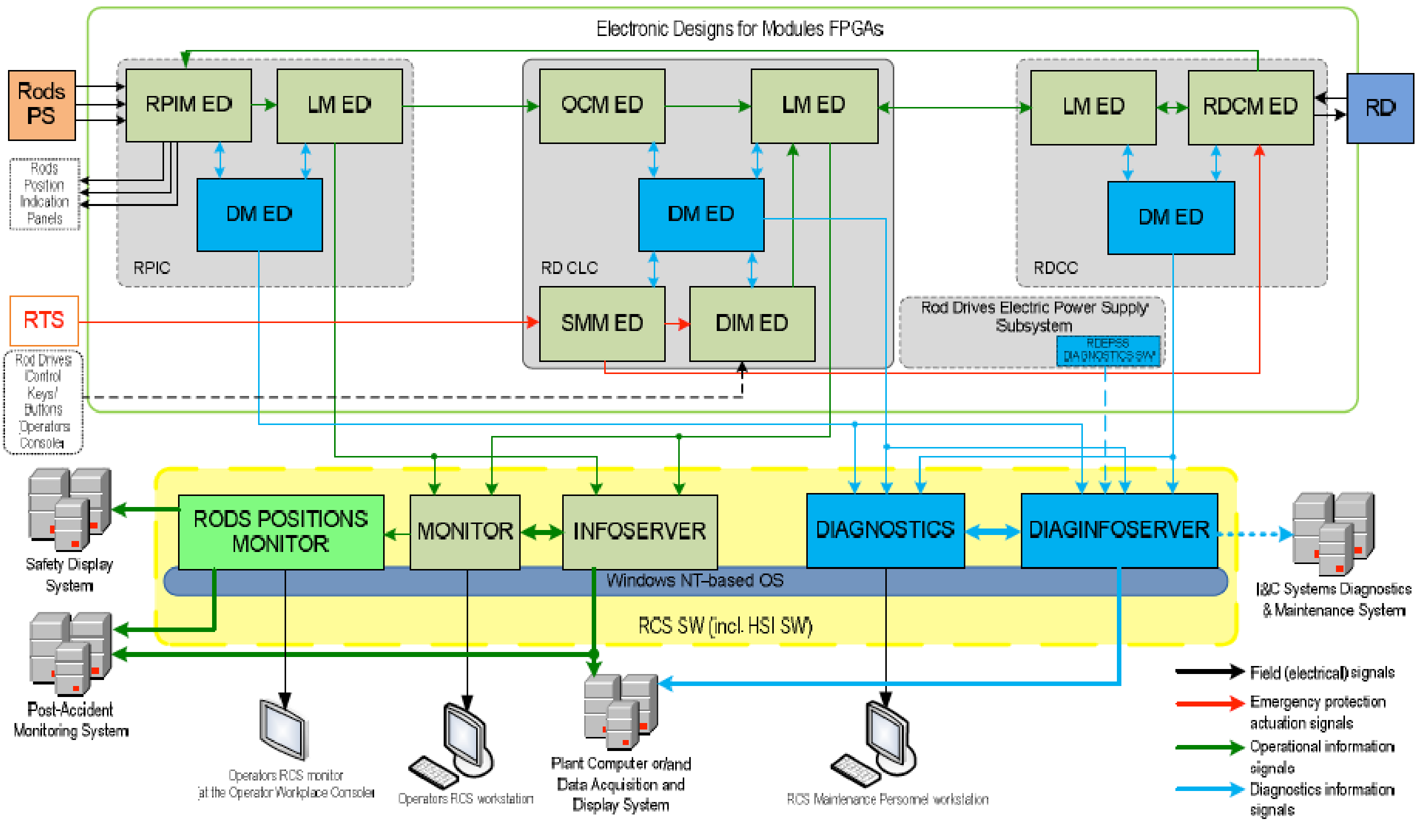
2.0 RADIY™-Based Rod Control System Software and FPGA's Electronic Designs Firmware Architecture

All field signals processing & monitoring, control logic and diagnostics algorithms and functions are implemented in the different modules FPGAs Electronic Designs (ED) firmware without using any type of Operational Systems and without any needs to use of software (SW) or computers/servers hardware (HW) to make RCS completely reliable and safely operable.

RCS application SW (including HSI SW) based on the Windows NT-compatible Operational Systems includes specific RODS POSITIONS MONITOR & SERVER SW application and basic for RADIYTM-based I&C Systems HSI SW applications, such as MONITOR, INFOSERVER, DIAGNOSTICS and DIAGINFOSERVER. All mentioned SW applications runs on the servers installed in the RCS Workstation Cabinets (RCS WSC) and use received by onedirectional communication lines information from the ED firmware of Logic Modules and Diagnostic Modules installed in all RCS cabinets.

General architecture of the RADIYTM-based RCS SW and EDs firmware is presented on the Figure 1.

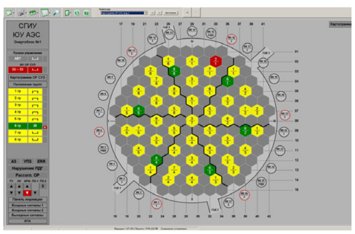
Figure 1 | General architecture of RCS software and Electronic Designs firmware for PWR-type reactors



3.0 RADIY™-Based Rod Control System Human-System Interface Software Applications Overview

RODS Positions Monitor SW

RODS POSITIONS MONITOR SW application is designed to collect, process, analyze and visualize at the operator workplace displays the main operating parameters of the Control and Safety Rods Positions in their groups or all at once in the reactor core mode.



SW application main functions:

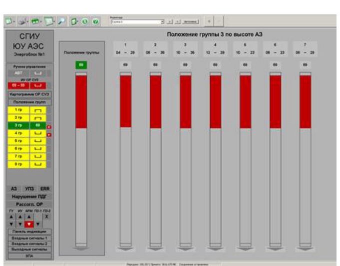
» on-line real Rods positions situation monitoring and proper/abnormal functioning of the control logic algorithms monitoring;

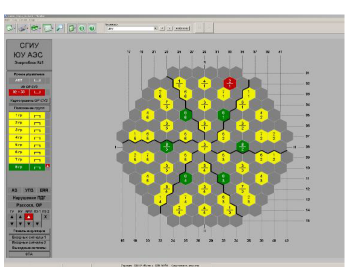
» providing visualization of Rods precisely defined positions and analysis tools for RD control logic status information visualization based on the on-line data processing or using archive records from WSC servers; and

» monitoring data documenting (using printing or recording on CD/DVD).

Monitor SW

MONITOR SW application is designed to collect, process, analyze and visualize at the operator workplace displays all Rod Control System operating parameters and interface signals.





SW application main functions:

» all RODS POSITIONS MONITOR SW functions, plus

» RCS control logic channels on-line properly functioning monitoring and signalization for operators in case of its logically abnormal functioning;

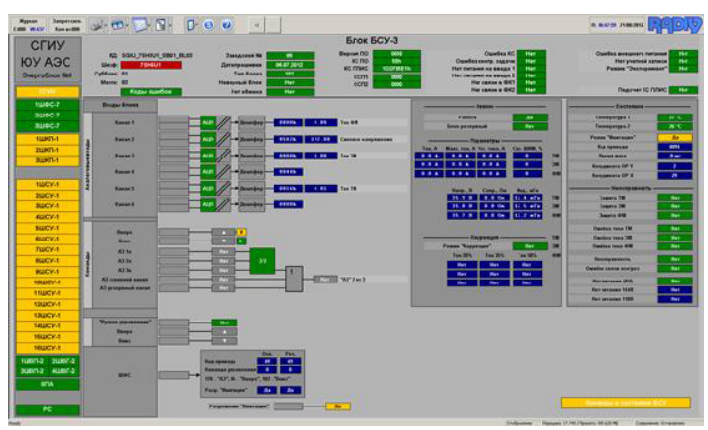
» providing visualization of the Rod Drives motors coils operability and analysis and testing tools for RD status checking using on-line or archive records data from WSC servers;

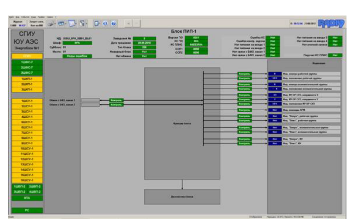
» on-line monitoring data and analyze results data exchange with INFOSERVER SW application (in the WSC servers); and

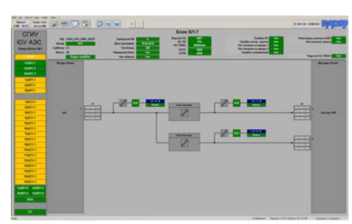
» RCS on-line functional data and signals analytics information visualization and documenting (using printing or recording on CD/DVD).

Diagnostics SW

DIAGNOSTICS SW application is designed to collect, process, analyze and visualize at the operators and maintenance personnel workplace displays all Rod Control System equipment operability and faults status parameters.





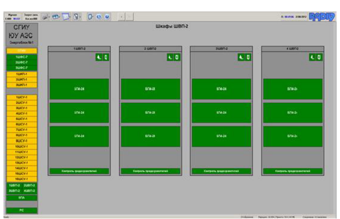


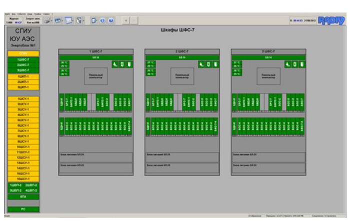
SW application main functions:

- on-line equipment operability situation monitoring;
- on-line monitoring of proper functioning of all interfaces, FPGA, power supply, and communication units in all system hardware modules;
- providing visualization of all equipment actual status;
- provide testing tools and faults analysis tools based on the on-line diagnostics data processing or using diagnostics archive records from WSC servers;
- on-line control logic channels circuits proper functioning monitoring and signalization for operators in case of its abnormal functioning;
- providing visualization of the equipment operability status checking (testing) using on-line or archive servers records data;
- on-line monitoring data and faults analyze results data exchange with DIAGINFOSERVER SW application (in the WSC servers); and
- RCS operability and interface signals analytics information visualization and documenting (using printing or recording on CD/DVD).

Info-Server and Diag-Info-Server SW

INFOSERVER and DIAGINFOSERVER SW applications is designed to receive, collect, archive all real-time (on-line) and analytics information, received from all RCS equipment and corresponding monitoring SW applications, and transmit it to the connected Plant / Unit information systems (according to the Unit I&C systems design architecture) or to the monitoring SW applications for data processing (analyze) and visualization by the operators and/or maintenance personnel requests.





SW applications main functions:

- on-line functional state signals or diagnostics data receiving, collection and archiving (from all RCS LMs and DMs and RDEPSS diagnostics SW);
- on-line RCS functional or diagnostics operability data transmitting to the connected Plant / Unit information systems (PAMS, Plant Computer, etc.); and
- previously archived monitoring and analytics results data exchange with corresponding MONITORs or DIAGNOSTICS SW applications (by requests).

3.0 Rod Control System Implementation Experience & Timeline

Between 2006 and 2012 years different sets of the RADIY™-based RCS equipment (full sets of one-channel RCS structures) have been 4 times tested in real normal and abnormal (extreme) operation conditions, including testing on the vertical test benches which are simulates the real-life operating modes with typical rods, at water temperatures in the rods testing column 20±10°C, 140±20°C, 290±30°C (vertical “cold” and “hot” test-benches) in the OJSC Experimental Design Bureau HYDROPRESS - rod drives design and manufacturing company of the State Corporation ROSATOM (Russian Federation), trial operation on Unit 1 with the VVER-1000 reactor of Zaporozhe NPP (this system was in operation in 2006 year), testing on the vertical test bench of South Ukraine NPP (in 2009).

RADIY™-based RCS’s equipment showed functioning validity on real signals (with forming the RD movement commands, its position displaying and control) as well as comprehensiveness of the circuit and design decisions and their compliance with all the operational and functional requirements, given in the Technical Specification (TS). The contents of TS was confirmed and approved by the all operating NPPs of Ukraine with WWER-1000 and WWER-440 reactors type, approved by State Nuclear Regulatory Committee (Inspectorate, since 2010) of Ukraine and OJSC Experimental Design Bureau HYDROPRESS (Russian Federation). All this equipment passed safety assessment and expertise by the State Enterprise “State

Scientific and Technical Center on Nuclear and Radiation Safety" of the State Nuclear Regulatory Committee (Inspectorate) of Ukraine. Results of tests and trial operation, given in the test & operational reports and protocols, certify on comprehensiveness and sufficiency of the design solutions, implemented in the system, as well as on enhancement of Rod Drives control characteristics.

Simplicity of maintenance and learning of the new equipment by the NPP personnel were recognized during trial operation of RADIY-based RCS equipment.

Based on the above mentioned results in 2012 first full set of the RADIY-based RCS have been successfully put in operation in the Unit 1 of the South-Ukraine NPP with WWER-1000 PWR-type reactor.

Figure 2 | RPC Radiy RADIY™-based RCS for WWER-1000 type reactors implementation time-line