Task analysis

Project: Automated cooling control system for the secondary circuit of a nuclear power plant

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**1. General description of the system**

The project involves the development of an automated cooling control system for the secondary circuit of a nuclear power plant. This system controls and regulates the circulation of the coolant (water) through the heat exchanger, where steam from the primary circuit transfers heat to the secondary coolant. The system plays a critical role in ensuring the safe and stable operation of the reactor.

Automation of the cooling circuit eliminates the human factor and increases the reliability of equipment operation. The project includes control of the main and backup pumps, automatic temperature control via a control valve, and an emergency alarm system in case of deviation of process parameters from acceptable values.

The development is implemented using an industrial controller (SPS), operator panels (HMI), and electrical circuit design tools in the EPLAN environment. The project simulates a realistic version of an industrial system and can be used as a demonstration of competencies in the automation of critical technological processes.

**2. Automation objectives**

The automation of the cooling circuit solves tasks that are difficult for humans to perform and that must be carried out as quickly and accurately as possible for the safety of the facility itself and the primary circuit of the nuclear power plant. The automatic control system is designed to ensure stable and safe operation of equipment by eliminating the human factor, responding promptly to parameter changes, and providing complete visualisation and diagnostics of processes.

Within the framework of the project, automation solves the following tasks:

• Automatic switching on and off of pumps depending on the set parameters of cooling water pressure and temperature, with priority given to the use of the main pump;

• Temperature control in the circuit using an executive control valve based on feedback from temperature sensors;

• Emergency shutdown of the system or transfer to a safe state when process parameters (temperature, pressure, flow) exceed permissible limits;

• Automatic switchover to the backup pump in case of failure or overload of the main pump, followed by an alarm on the HMI;

• Visual control of current parameters of temperature, pressure, status of pumps and actuators via the HMI panel;

• Display and recording of emergency messages, warnings and event logs for subsequent analysis;

• Testing of equipment in manual mode via the HMI when maintenance or diagnostics are required;

• Ensuring a high level of reliability and fault tolerance through the use of equipment redundancy and condition monitoring.

Thus, automation is aimed at ensuring a continuous technological process, rapid response to emergency situations and simplifying operator control without compromising safety.

**3. Project scope**

This project only models the automated cooling control system of the second circuit of a nuclear power plant at the level of the local PLC (SPS) and operator interface (HMI). The project does not claim to fully reflect all physical processes occurring in a nuclear facility, but focuses on demonstrating the key principles of industrial automation.

The project includes:

• Modelling of pumps (main and backup) with logic for controlling their activation, deactivation and switching;

• Temperature and pressure sensors, whose signals are processed by the system for regulation and emergency response;

• A control valve that regulates the temperature of the coolant;

• Emergency alarm when parameters exceed acceptable limits;

• Modelling of redundancy logic and transition to a safe state;

• Operator interface (HMI) for visualising parameters, control and displaying warnings;

• EPLAN design environment for circuit implementation of the control system.

The project does not include:

• Physical equipment — pumps, pipes, valves, etc. are not manufactured or used in reality;

• Real nuclear processes — heat transfer from the primary circuit, radioactivity and other physical phenomena are not simulated;

• The top-level SCADA system responsible for the comprehensive control of the entire nuclear power plant, including archiving, dispatching, and control of many other nodes;

• Equipment diagnostics and self-testing systems at the service level;

• Network architecture and cybersecurity, except for the basic model of PLC and HMI interaction;

• Integration with other parts of the plant, such as the power supply system, access control and other external subsystems.

Thus, the scope of the project is limited to the local automation of the secondary circuit cooling section and the modelling of the corresponding equipment operating logic, with the aim of teaching and demonstrating skills in the design of reliable control systems.

**4. Safety and reliability**

The safety and reliability of the automated control system are priority aspects of the design, especially given the critical importance of the cooling circuit in the structure of a nuclear power plant. The system is implemented taking into account the principles of fault tolerance and ensuring predictable behaviour in emergency situations.

The main mechanisms for ensuring safety and reliability are as follows:

1. Pump redundancy (N+1):

The system provides for both a main and a backup pump. If the main pump fails (due to lack of feedback, overload or exceeding the start-up time), the backup pump is automatically activated, with a parallel signal sent to the operator.

2. Equipment failure monitoring via feedback:

Equipment (pumps, valves, sensors) is monitored for the presence of a feedback signal. If there is no confirmation of command execution (for example, the pump has not entered operating mode), an emergency message is generated and the backup channel is activated, if available.

3. Protection against overheating and pressure drops:

The system constantly monitors temperature and pressure. If the set limits are exceeded, the system:

• Takes corrective action (e.g., adjusts the valve);

• If the problem cannot be resolved, switches the system to safe mode (e.g., shuts down the pumps and blocks the start-up);

• Informs the operator via HMI and audible/visual alarms.

**4. Alarm to the operator in any emergency situation:**

All deviations from the norm are displayed on the HMI with corresponding colours and text messages. An audible alarm is also activated. The operator receives visual confirmation of the cause of the emergency and the current status of all components.

5. Recording events and emergencies in the log:

The system records all key events, errors and emergency situations in a log that can be viewed via the HMI. This allows for subsequent analysis and fault diagnosis.

6. Equipment test mode:

As part of maintenance and diagnostics, it is possible to manually check the equipment via the operator interface. This allows potential failures to be identified without starting the main system.

7. Simple and understandable emergency shutdown logic:

In the event of critical failures (loss of communication with sensors, simultaneous failure of the main and backup pumps), the system suspends operation, switches to emergency mode and informs the operator, preventing uncontrolled behaviour.

Thus, the design system provides a high level of reliability, fault tolerance and timely response to emergency situations, which is critical for ensuring the safe operation of a nuclear power plant.

**5. Hardware and software platform**

The project is implemented using reliable hardware and cross-platform software, which ensures flexibility in development, the ability to model, and compliance with industrial automation standards.

Hardware platform:

1. Siemens S7-1200 PLC

A programmable logic controller that implements the control logic for pumps, sensors and actuators. It is used in conjunction with CODESYS through support for IEC 61131-3 standards (via compatible firmware or emulation during simulation).

2. Operator panel (HMI)

HMI is implemented in the CODESYS environment with visualisation of the control process, display of alarms, current parameters and operating modes. In real implementation, an industrial panel supporting WebVisu or directly integrated CODESYS visualisation can be used.

Software:

3. CODESYS

A cross-platform development environment used for:

• Programming PLC logic (ST, LD, FBD, etc.)

• Developing the HMI interface via CODESYS Visualisation

• Testing logic and simulating system operation

4. EPLAN Electric P8

Used for developing and designing electrical diagrams: PLC connections, sensors, actuators, power supply and protection, as well as marking and specifications.

5. Documentation – Microsoft Word / PDF

All project and explanatory documentation, including technical specifications, logic descriptions, operating principles and specifications, is prepared in publicly available formats.

Additionally:

6. CODESYS WebVisu

Used to display the operator interface in a web browser – during simulation or when deployed on a panel with WebVisu support.

7. CODESYS Control Win (or Raspberry Pi / simulation)

In the absence of a physical controller, PLC software emulation is used to verify the project's operation.

Thus, the project is based on a reliable hardware platform and flexible CODESYS software, which allows you to develop and simulate a complex control system without being tied to highly specialised manufacturer tools.

6. Input and output signals (general description)

The system uses standard types of input and output signals typical for industrial automation systems. The signals provide continuous monitoring of parameters and control of actuators.

Input signals:

1. Temperature sensors (analogue signals, 4–20 mA or 0–10 V)

Measure the temperature of the coolant at the inlet and outlet of the heat exchanger.

2. Pressure sensors (analogue)

Monitor the pressure in the cooling circuit to protect against pressure drops and leaks.

3. Level/flow sensors (discrete or analogue)

Monitor the presence of coolant and the stability of circulation.

4. Feedback signals from pumps and valves (discrete)

Provide information on the status (operating/not operating, open/closed) and confirm the execution of commands.

5. Control buttons (manual/auto, emergency stop, etc., discrete)

Allow the operator to manually switch modes or shut down the system in an emergency.

Output signals:

1. Pump control (discrete)

Switching the main and backup pumps on/off.

2. Control valve control (analogue or PWM signal)

Adjustment of the coolant flow rate depending on the temperature.

3. Signal lamps/indicators (discrete)

Display of the current status of the equipment (operating, standby, emergency).

4. Emergency alarm (discrete, for audible and visual alerts)

Activation in case of critical parameter deviations.

5. Data transfer to HMI (internal interface)

For visualisation of all parameters and control via a graphical interface.

Thus, the project uses a combination of analogue and discrete inputs/outputs to provide complete control and management of the cooling circuit.

**7. Expected project outcome**

The project will result in the creation of a fully functional model of an automated cooling circuit control system for a nuclear power plant with visualisation and simulation capabilities. The main focus is on reliability, safety and the demonstration of key competencies in the field of industrial automation.

Expected results:

1. PLC operating logic

A fully implemented CODESYS-based control program, including automatic and emergency pump control, temperature regulation, sensor signal processing, and redundancy.

2. Electrical diagrams in EPLAN

A set of diagrams showing equipment connections, power circuits, control signals and emergency protection.

3. HMI interface

A visual interface developed in CODESYS with display of current parameters, equipment status, manual control option and emergency indication.

4. Test simulation/video of system operation

Demonstration of logic operation in a simulation environment (via CODESYS Control Win or WebVisu) with simulation of signals and system responses.

5. Complete technical documentation

Includes technical specifications, logic description, signal structure, diagrams, start-up instructions and explanatory notes — formatted in Microsoft Word and exported to PDF.

Thus, the project will provide a comprehensive demonstration system that is close to a real industrial solution, with the possibility of using it as a training, demonstration or conceptual model.