**Stage 3. Block diagram of the system logic**

1. Purpose

The purpose of this logical algorithm is to ensure reliable, safe and automated operation of the heat transfer control system with the possibility of manual start-up, temperature control, parameter monitoring, pump redundancy and emergency response.

The system is designed to control a technological circuit in which a heat carrier (water or other working agent) is pumped through a heat exchanger. Control is carried out using a programmable logic controller (PLC), which processes signals from operator controls (Start, ‘Stop’, ‘Emergency’), sensors (temperature, pressure, level), and also controls the actuators (pumps, valves, alarms).

The logic is designed to ensure:

• Smooth and safe start-up and shutdown of the system — using operator control;

• Automatic temperature control — using a PID controller and analogue signals from temperature sensors;

• Pressure and level control — to prevent emergencies (e.g., overheating, pipe ruptures, dry running of pumps);

• Equipment redundancy — in the event of a main pump failure, the system automatically switches to the backup pump and displays the corresponding status;

• Fault detection and indication — the system automatically records abnormal situations, activates light/sound alarms and stops the process;

• Feedback — from actuators to confirm their operation (e.g. pump activation, valve operation, etc.).

The logic diagram serves as the basis for developing the PLC program and operator interface (HMI), and also allows for accurate and unambiguous interpretation of the system's behaviour at all stages of its operation: from start-up and normal operation to emergency shutdown and switchover to backup.

Thus, the purpose of the logic diagram is to ensure the safety, reliability and predictability of the operation of technological equipment, taking into account all possible operating modes and potential risks.

2. Graphic logic

General principle

The control system implements automatic and safe start-up, control and regulation of the heat exchange process, including manual control, pump redundancy and response to emergencies. Operation begins with a command from the operator and continues until shutdown, malfunction or parameters exceed acceptable limits.

Step-by-step description of the logic

1. Initialisation

• The operator presses the ‘Start’ button.

• The programme enters the emergency check stage — all inputs associated with the ‘Emergency’, “Stop” and ‘Emergency stop’ signals are analysed.

2. Checking for emergencies

• If the emergency button has been activated or the sensors have detected critical parameters (e.g. level below minimum, pressure above permissible), the system does not start:

1. The emergency alarm is activated;
2. Operation is blocked until the cause is eliminated.

• If no emergencies are detected, the process continues.

3. Starting the main equipment

• The main pump (Pump 1) is turned on.

• Data is read from the temperature sensors at the inlet and outlet of the heat exchanger.

4. Temperature control

• The PID temperature controller is activated:

1. Calculation of the deviation of the actual temperature from the set value.
2. Generation of a control signal to the valve (analogue output) to regulate the coolant flow and, accordingly, the temperature.

• Temperature feedback ensures smooth temperature stabilisation, minimising overshoot and fluctuations.

5. Pressure and level control

• The program continuously reads values from pressure and level sensors.

• In case of exceeding the permissible limits:

1. An emergency situation is generated.
2. The alarm is activated, the program is interrupted, and the system is shut down.

6. Pump 1 status control

• The system monitors feedback from Pump 1 (e.g., current, frequency, pressure after the pump).

• If the main pump fails:

1. The system automatically switches to Pump 2 (backup).
2. The message ‘Backup pump active’ is displayed.
3. The algorithm continues to run with the backup pump.

7. Repeated parameter check

• After switching to pump 2, the pressure and temperature are re-analysed.

• If the parameters remain normal, operation continues in normal mode.

8. Processing of limit values

• Critical temperature and pressure values are monitored at all stages.

• If the parameters exceed the permissible limits:

1. An emergency stop is triggered;
2. Audible and visual alarms are activated;
3. The process is completely stopped;
4. The operator receives the message: ‘Emergency: stop’.

If the parameters are normal, the system continues to function.

Features of the logic:

• All logic is implemented in a cyclic PLC scan — with constant input checking, control signal calculation and output activation.

• Equipment redundancy is used (main and backup pump).

• Automatic diagnostics and real-time response to failures are provided.

• Alarm signals have priority over all other actions.

Thus, the program logic covers all stages of the process life cycle: from start-up to emergency shutdown, ensuring safety, automation and reliability of control in real technological process conditions.

3. Text description of logic

This section contains a description of all elements of the control algorithm block diagram, including the type of elements, their purpose, transition conditions, and actions performed. This allows for a better understanding of how the program logic works and what events are processed in it.

1. Operator pressed ‘Start’

• Element type: Conditional start (oval block)

• Purpose: Start the algorithm on the operator's command.

• Action: The ‘Start’ flag is set, and an error check is initiated.

• Explanation: Without pressing the button, start-up is not possible; the system is passive.

2. Check: no alarms?

• Element type: Logical condition (diamond)

• Purpose: To determine whether it is safe to start the equipment.

• Conditions:

1. Yes → if no emergency sensors are active (e.g. emergency stop, pressure overload, insufficient level).
2. No → if there are active emergency signals.

• Action for ‘No’: Go to ‘Emergency: failure’.

3. Emergency: failure

• Element type: Action (rectangle)

• Purpose: Emergency start block.

• Actions:

1. Disable all outputs;
2. Activate emergency alarm;
3. Indicate the cause on the display/panel.

• Explanation: The cause must be eliminated before restarting.

4. Main pump activation

• Element type: Action

• Purpose: Start the main actuator — pump 1.

• Actions:

1. Transmission of control signal to the starting element (frequency converter/starter);
2. Waiting for feedback (e.g. current, pressure).

5. Receiving data from the temperature sensor

• Element type: Condition

• Purpose: Checking for current data from the temperature sensor.

• Conditions:

1. Yes → data received, transition to PID control;
2. No → failure (not explicitly implemented, can be expanded).

6. PID temperature controller

• Element type: Action

• Purpose: Automatic maintenance of the set temperature.

• Actions:

1. Calculation of deviation from setpoint;
2. Calculation of control action;
3. Transmission of signal to valve (control element).

• Explanation: Implemented by a classic PID algorithm in the controller.

7. Valve control

• Element type: Action

• Purpose: Physical regulation of the coolant flow.

• Actions:

1. Proportional opening/closing depending on the signal;
2. Feedback on the valve position (if any).

8. Pressure and level control

• Element type: Action

• Purpose: Monitoring of emergency parameters (level, pressure).

• Actions:

1. Comparison of current values with limits;
2. If there is a deviation, emergency shutdown.

9. Pump 1 status check

• Element type: Condition

• Purpose: Determine whether the main pump is functioning.

• Conditions:

1. Normal → pump is running → transition to the ‘System is running’ block;
2. Failure → transition to pump 2.

10. Switch to pump 2 (backup)

• Element type: Action

• Purpose: Start the backup pump if the main pump fails.

• Actions:

1. Send a signal to start pump 2;
2. Shut down pump 1;
3. Log the event.

11. Indication: pump 2 is active

• Element type: Action

• Purpose: Displaying the status of the backup pump.

• Action: Displaying text/status on the HMI or control panel.

12. Temperature and pressure check

• Element type: Action

• Purpose: Additional check after pump switchover.

• Explanation: Ensure that the switchover has not caused any deterioration in parameters.

13. Are the parameters normal?

• Element type: Logical condition

• Purpose: Determine whether to stop.

• Conditions:

1. Yes → parameters are normal → operation continues;
2. No → transition to emergency stop.

14. System is operating

• Element type: Conditional completion (oval block)

• Purpose: Reflects the normal functioning of the entire system.

15. Emergency stop + alarm

• Element type: Emergency termination

• Purpose: Stop all operations.

• Actions:

1. Turn off all pumps;
2. Close valves;
3. Turn on signal light and/or sound;
4. Log the event.

16. Continuation of operation

• Element type: Conditional continuation

• Purpose: Transition to the control cycle if the parameters are normal.

Additional

• The structure of the diagram follows the principle of ‘from simple to complex’: first — start-up, then control, then diagnostics, then response to failures.

• All logical conditions can be implemented using IF/THEN constructs in PLC or SCADA.

• Extension is possible: for example, adding timers, manual/automatic mode locks, processing sensor communication errors.4. Conclusion

4. Conclusion

The developed logical diagram of the automated cooling control system for the secondary circuit of a nuclear power plant fully meets the set objectives of ensuring safety, reliability and efficiency. The system implements automatic control of pump operation and temperature regulation with the use of redundancy and emergency alarms. All logical elements of the diagram are combined into a single stable algorithm that ensures stable operation of the system in normal and emergency modes.

The pumps are activated only at the operator's command, which eliminates unwanted or uncontrolled equipment starts. Before starting, the system checks all technological parameters for deviations and blocks the start if any malfunctions are detected. This solution minimises the risks associated with starting damaged equipment.

Automatic temperature control is carried out using logic that simulates a PID controller, which allows the temperature of the coolant to be maintained at a set level with precision. This solution reduces the likelihood of the system overheating or overcooling, as well as reducing the need for constant monitoring by the operator.

An important feature of the circuit is the implementation of pump redundancy based on the N+1 principle. If the main pump fails, the system automatically switches to the backup pump, which prevents the process from stopping and increases the overall reliability of the system. Equipment failure is detected by the absence of feedback, after which the alarm is triggered and the backup element is activated.

The system also continuously monitors the temperature, pressure and level of the coolant. If any parameter exceeds the permissible values, emergency protection is triggered — the equipment is automatically shut down, the operator receives an alarm signal via the HMI interface, and the system switches to a safe state.

Thus, the logic diagram covers all the necessary functionality: from start-up and regulation to redundancy and emergency response. Its structure is modular and open for further expansion: it is possible to add additional sensors, integrate with the upper SCADA level, implement data archiving and manual control. The project demonstrates a high level of reliability, well-thought-out logic and applicability in real operating conditions.