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Design of the Safety Control of the Cooling System

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Abstract: The article deals with the design of the control system of the technical equipment for cooling the system. During the solution, the safety point of view had to be taken into account, so it was necessary to design a multi-stage cooling system, and at the same time it was also necessary to take this into account when designing the control system.

Keywords: Control system, sensor, cooler, human machine interface

1. Introduction

For the design of control systems, it is important that the control system is tested in the form of simulation and possibly in combination with hardware as a hardware-in-the-loop simulation before the actual implementation. These simulations will confirm the correctness of the designed algorithm and at the same time it will be possible to tune the system to its final form. The main advantage of simulation is that we can bring the control system to a state that cannot be tested with a real system, because it would mean a security threat or enormous material damage could occur. It is thus possible to test the control system even in abnormal situations, which, however, may occur and the risk of their occurrence cannot be neglected [1-14].

The goal is to design a control system implemented by a PLC controller that will control the cooling of the technological equipment. Cooling is a key system for ensuring the safe operation of the workplace, so it is necessary to solve it in several stages. The requirements for the operation of the device are:

» *Temperature $T > 100°C$ cooling system 1 (CS1) will activate and temperature sensor 1 (T_1) will take readings.*

» *Temperature $T > 150°C$ both cooling system 1 (CS1) and cooling system 2 (CS2) will activate along with temperature sensor 2 (T_2).*

» *Temperature $T > 200°C$ cooling system 1, cooling system 2, cooling system 3 will activate along with temperature sensor 3 (T_3).*

» *Temperature $T > 250°C$ every cooling system will active which includes CS1, CS2, CS3 and cooling system 4 (CS4) along with temperature sensor 4 (T_4).*

Let us assume from the above given condition:

If,

» $T < 100°C$ *then,* $T_1 = 0$ *and* $CS1 = 0$; $T > 100°C$ *then* $T_1 = 1$ *and* $CS1 = 1$.

» $T < 150°C$ *then,* $T_2 = 0$ *and* $CS2 = 0$; $T > 150°C$ *then* $T_2 = 1$, $CS1 = 1$ *and* $CS2 = 1$.

» $T < 200°C$ *then,* $T_3 = 0$ *and* $CS3 = 0$; $T > 200°C$ *then* $T_3 = 1$, $CS1 = 1$, $CS2 = 1$ *and* $CS3 = 1$.

» $T < 250°C$ *then,* $T_4 = 0$ *and* $CS4 = 0$; $T > 250°C$ *then* $T_4 = 1$, $CS1 = 1$, $CS2 = 1$, $CS3 = 1$ *and* $CS4 = 1$.

To create the logical functions will use only two operators 0 and 1. Inputs and outputs also available in 0 and 1. 0 is false and 1 is true. From the above assumption, have 4 inputs (T1, T2, T3, and T4) and 4 outputs (CS1, CS2, CS3 and CS4). From these

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inputs and outputs, must solve the truth table to derive the Boolean expression, implement the logical functions, logical circuit design and ladder diagram of PLC program.

2. Math model expression

A truth table was used to create a mathematical model and the system was modeled as a combinational logic system in which other functions will be incorporated at a later stage of the design.

Laws of Boolean Algebra expressions have been developed to help reduce the number of logic gates needed to perform a specific logic operation resulting in a list of functions or statements commonly known as the Laws of Boolean Algebra. The distinguishing aspect of Boolean logic is that it deals only with the study of binary variables. Most frequently Boolean variables are presented with the binary values of 1 (true) or 0 (false). Variables also can have more complex interpretations, like in pure mathematics. Boolean algebra is also known as binary algebra.

Boolean algebra is different from fundamental algebra as the latter deals with numerical operations and the former deals with logical operations. Basic algebra is expressed using basic mathematical functions, such as addition, subtraction, multiplication, and division, whereas Boolean algebra deals with conjunction (AND), disjunction (OR), and negation (NOT).

From the truth table derived the Boolean expression as follows with the help of basic logical operations conjunction (AND), disjunction (OR) and negation (NOT).

Boolean expression for Cooling System 1 is:

$$CS_2 = (T_1 + T_2 + T_3 + T_4).(\overline{T_1} + T_2 + T_3 + T_4) \tag{1}$$

Boolean expression for Cooling System 2 is:

$$CS_2 = (T_1 + T_2 + T_3 + T_4).(\overline{T_1} + T_2 + T_3 + T_4) \tag{2}$$

Boolean expression for Cooling System 3 is:

$$CS_3 = (T_1 + T_2 + T_3 + T_4).(T_1 + \overline{T_2} + T_3 + T_4).(\overline{T_1} + T_2 + T_3 + T_4).(\overline{T_1} + \overline{T_2} + T_3 + T_4) \tag{3}$$

Boolean expression for Cooling System 4 is:

$$\begin{aligned} CS_4 = {} & (\overline{T_1} \cdot \overline{T_2} \cdot \overline{T_3} \cdot T_4) + (\overline{T_1} \cdot \overline{T_2} \cdot T_3 \cdot T_4) + (\overline{T_1} \cdot T_2 \cdot \overline{T_3} \cdot T_4) + (\overline{T_1} \cdot T_2 \cdot T_3 \cdot T_4) \\ & + (T_1 \cdot \overline{T_2} \cdot \overline{T_3} \cdot T_4) + (T_1 \cdot \overline{T_2} \cdot T_3 \cdot T_4) + (T_1 \cdot T_2 \cdot \overline{T_3} \cdot T_4) + (T_1 \cdot T_2 \cdot T_3 \cdot T_4) \end{aligned} \tag{4}$$

From theses expressions going to design the logical functions.

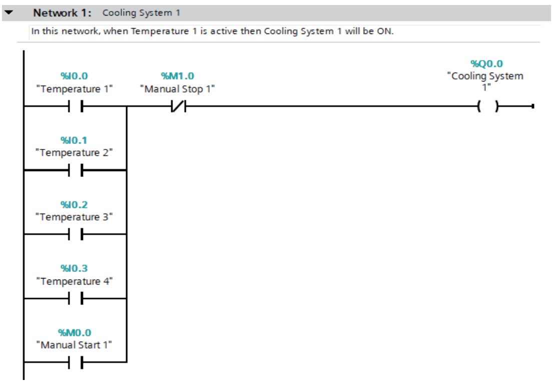

Figure 1: Ladder diagram of Cooling System 1.

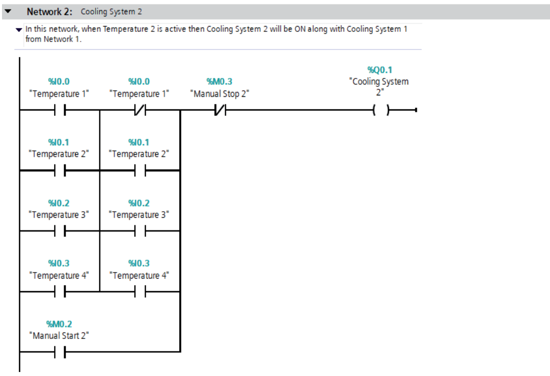

Figure 2: Ladder diagram of Cooling System 2.

3. Ladder diagram construction

Constructed the following ladder diagrams according to truth table and Boolean expressions. Ladder diagram of Cooling System 1 is shown on figure 1. Ladder diagram of Cooling System 2 is shown in figure 2. Ladder diagram of Cooling System 3 is shown on figure 3 and Cooling System 4 is shown on figure 4.

In above ladder diagrams, there are multiple options to turn ON and turn OFF each Cooling System. Manual Start and Manual Stop by using Memory tags to have been added into structure of every ladder diagram to turn ON and turn OFF Cooling Systems individually. It is not possible to activate and deactivate every system at the same time by using ladder diagram simulation. But it is possible to do in HMI (Human-Machine Interface).

For applications of this type, the use of safety PLC systems is preferred (fig. 5). The safety PLC incorporates many diagnostic functions to detect any possible internal fault in the hardware or

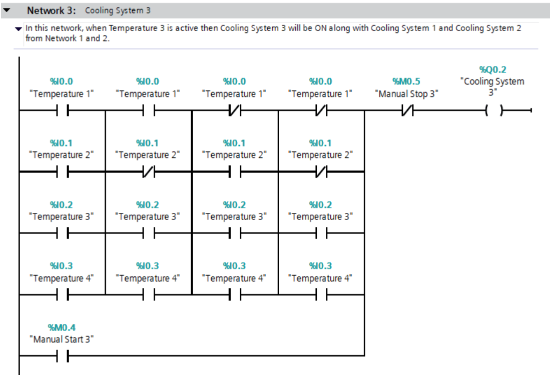

Figure 3: Ladder diagram of Cooling System 3.

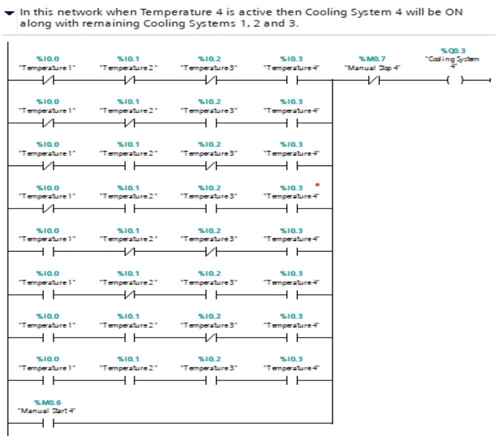

Figure 4: Ladder diagram of Cooling System 4.

firmware, so that a failure in the PLC does not cause any "unsafe" situation. These diagnostics reduce the rates of dangerous undetected failures and the probability of failures used in the SIL calculations. There are many diagnostic functions in the safety PLC, both CPU and memory as inputs, outputs, and communications, and that logically carries an additional cost. It is important to note that the design of a safety system must consider the entire "SIS", i.e.: the PLC, field devices, electrical supplies, sensors, actuators, control cabinet design, software, etc. Statistically there are more failures in sensors and actuators than in the PLC. Safety Instrumented Systems (SIS) are installed in Process Plants to mitigate process hazards by taking the process to a "safe state" when predetermined set points have been exceeded or when safe operating conditions have been transgressed.

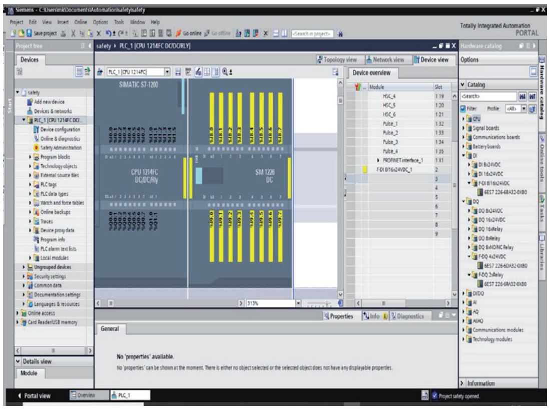

Figure 5: Safety PLC design.

4. Design of user interface HMI

Human machine interface is designed for use by an operator who can monitor the process of the device and also has the ability to intervene in this process using process buttons and settings. The design of the main screen is in the figure 6. To design HMI, used lots of objects, graphics, and images to use and understand in an easy way. Every image and object are assigned to pushbutton to perform their assigned operations. Including the START and STOP button used pushbuttons to perform the operations. To show the screen names, usernames used I/O button. To show time and date used Time and Date button.

HMI can be used group people or users, to track who is operating, maintaining, and supervising the system used login system for emergency and security reasons. HMI can be used group people or users, to track who is operating, maintaining, and supervising the system used login system for emergency and security reasons

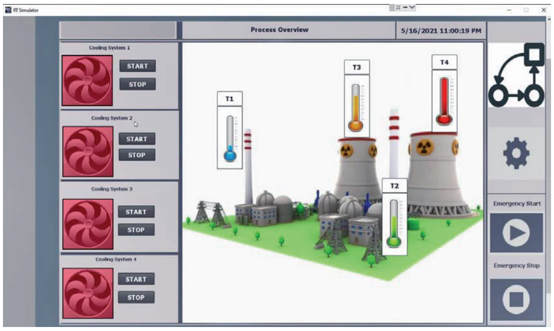

Figure 6: Main screen of Human-Machine Interface Design.

5. Simulations

The simulation will help determine the correctness of the design of the control system and draw attention to possible weaknesses of the designed system. This verification step in the control system design process is very important and necessary so that the designed system can later be implemented into a real system. Figure 7 shows security log in into HMI application.

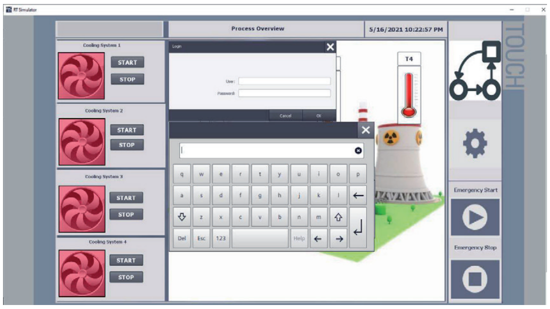

Figure 7: Log in to HMI.

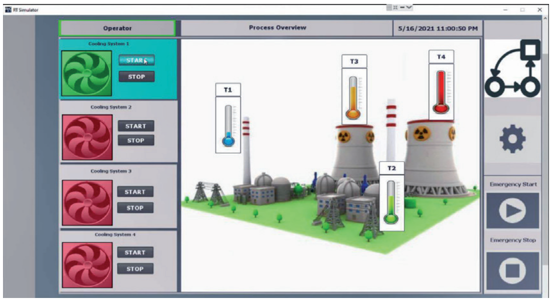

Figure 8: Cooling System 1 simulation.

Simulation of user start of cooling system 1 is tested on figure 8. When we click the START button Cooling System 1 will ON. To turn it OFF click the STOP. When we press Emergency Start Button, every cooling system will be ON. To turn OFF systems we can either STOP or Emergency Stop buttons (fig. 9).

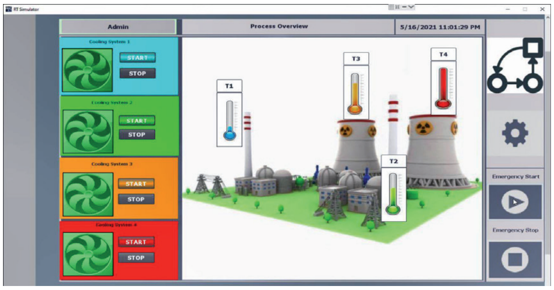

Figure 9: Emergency Start Simulation.

6. Conclusions

The simulation confirmed the correctness of the designed system, as well as crisis situations were correctly evaluated, and the control system responded correctly by starting the necessary cooling circuits. Applications of this type are designed as systems with redundancy, so even if one active cooling circuit is sufficient for the operation of the system, for the safety of the system it is necessary to increase the number of cooling systems in order to solve crisis situations. Seemingly unnecessarily applied additional systems must be used to provide replacement systems for the safe operation of the solved system.

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