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RAILWAY ELEMENTS COMMANDED, CONTROLLED AND MONITORED VIA PROGRAMMABLE LOGIC CONTROLLER SYSTEM

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This paper presents the design and implementation of a control and monitoring system for railway infrastructure using Programmable Logic Controllers (PLCs) and Human-Machine Interfaces (HMI). The system integrates critical railway elements—such as interlocking mechanisms, light signals, maneuver signals, and level crossing barriers—within a digital automation environment based on Siemens TIA Portal V18. Through ladder diagrams and sensor integration, the proposed solution ensures safe, conflict-free train operations by enabling real-time supervision and automation of railway components. Emphasis is placed on compliance with European safety standards (CENELEC), system modularity, and scalability. The study demonstrates the advantages of PLC-based control systems in enhancing operational reliability, reducing manual errors, and enabling predictive maintenance in modern railway stations.

Keywords: Railway industrial process, monitoring, control, programmable logic controller, human-machine interface, TIA PortalV18, Siemens, Railway network.

1. Introduction - Interlocking system

The interlocking system is a critical subsystem in railroad control systems, ensuring that train movements through stations, crossings, and other track configurations are executed without conflict. Modern interlocking systems incorporate HMI interfaces to improve control, monitoring and operational efficiency [1].

Interlocking Module (IM) refers to the location and positioning of signals, points, the totality of the command and control part, and other rail infrastructure to ensure that conflicting movements are avoided. This is achieved through the application of safety rules to prevent the possibility of accidents that may endanger the user, staff or passenger [1].

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Safety standards at European level are the standards realized by CENELEC and some ISO and EN standards [2, 3, 4, 5]. Examples are the CENELEC standards in the bibliography.

The integration of programmable logic controllers (PLCs) into the Romanian railway system is still in its early stages, being limited to pilot projects or isolated upgrades, in contrast to railway networks in Western Europe or Asia, where PLCs are a much more integral part of the command and control infrastructure, ensuring advanced automation of signaling, energy management, and operational safety.

The main functions of interlocking are:

- Route Setting: Configures rail elements to create a safe path for a train to follow;
- Conflict Avoidance: Ensures that there is no active route being used by two trains going in opposite directions (a route is a pair of tracks), and that it is impossible to set these routes;
- Locking: Locks the railway elements in their current position while a train is traversing a controlled section, to prevent their values from being altered either by unauthorized means or by accidents;
- Reset: Unlocks the state of the railway elements and returns them to their default state after the train has left the controlled section it was previously on [1].

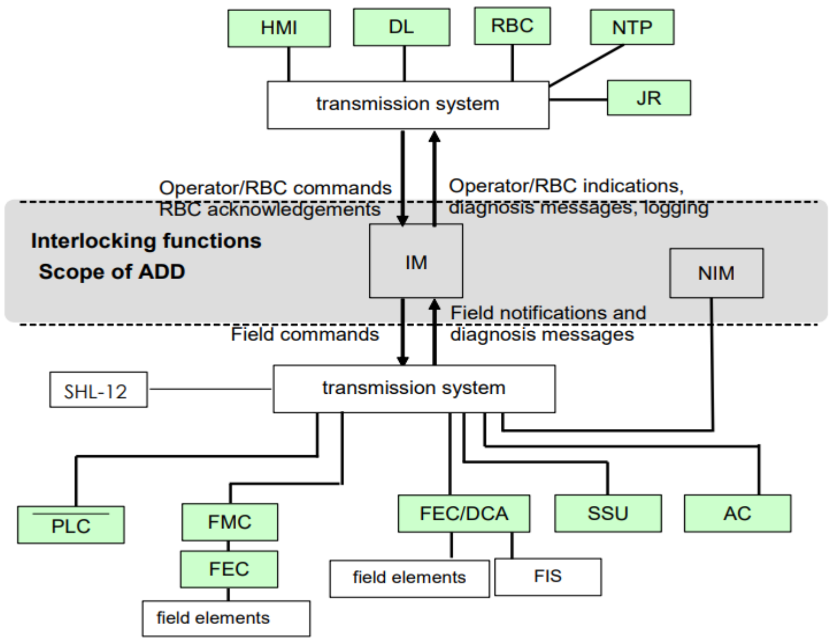

Fig. 1. Presentation of the interlocking system

The elements shown in Fig. 1 are: IM (Interlocking Module), RBC (Radio Block Center), NIM (Neighbour Interlocking Module), DL (Data Logger), JR (Juridical Recorder), AC (Axle Counter), SSU (Speed Supervision Unit), NTP (Network Time Protocol).

Interlocking system is of different types, it has evolved in the railroad industry. The main types are: mechanical interlocking, electromechanical interlocking, relay based interlocking, L90/L905 interlocking system, PIPC (Poste Informatique à technologie PC) system.

2. Railway sensorial systems

The rail industry relies on command and control systems to manage the movement of trains on tracks by means of sensor systems. The aim of these systems is to prevent collisions, ensure safe distances between trains and optimize the use of infrastructure. Railway signaling elements are the main means of communication between the control system and the train drivers [6, 7].

Rail signaling systems are inherently designed with fail-safe principles, ensuring that any failure brings the system to its safest state. For example, in the event of a signal failure, the system will display a "stop" appearance to prevent trains from moving unintentionally [8, 9]. Technological advances have led to the development of systems such as ETCS and Positive Train Control (PTC), which provide continuous, real-time communication between trains and command and control centers. These systems improve safety and increase operational efficiency by enabling higher train density and precise control [9].

Railroad signaling and control systems are an important part of safe and efficient railroad operation. Railway signals can be broadly categorized according to their location and functionality; the main types are outlined [10]. Color-light signals use red, yellow and green lights (or other color coding, depending on the country, standards, and the customer wish to implement it) to indicate stop, caution and advance conditions. These signals are considered fixed signals [10].

3. Railway elements commanded by Programmable Logic Controllers

The TIA Portal V18 (Totally Integrated Automation Portal) represents a milestone for Siemens in the field of industrial automation software, providing a complete and unified platform for engineering applications in the digital industry [11].

This release introduces new features designed to optimize workflows, increase productivity and support the modern technologies present in the new type of industry, namely Industry 4.0 [12]. The collaboration model in TIA Portal V18 builds on previous iterations, with each project that is used, in real-time, by a user, being automatically saved and stored, then synchronizing for other users working on the same project. The speed of data synchronization depends on the server load and Ethernet network speed, the presence or absence of a VPN (Virtual Private Network) [12]. This functionality imposes certain restrictions on the system configurations present in the project in TIA Portal, which cannot be changed by any user, but only by the user who created the project. This restriction is done either with a password or with user ID detection [11, 13].

Due to the complexity of the system, compilation times are longer, and responses are delayed. TIA Portal V18 introduces optimizations in data management and design compilation algorithms, which leads to reduced simulation and processing times [11]. Fig. 2 shows the control of a light signal.

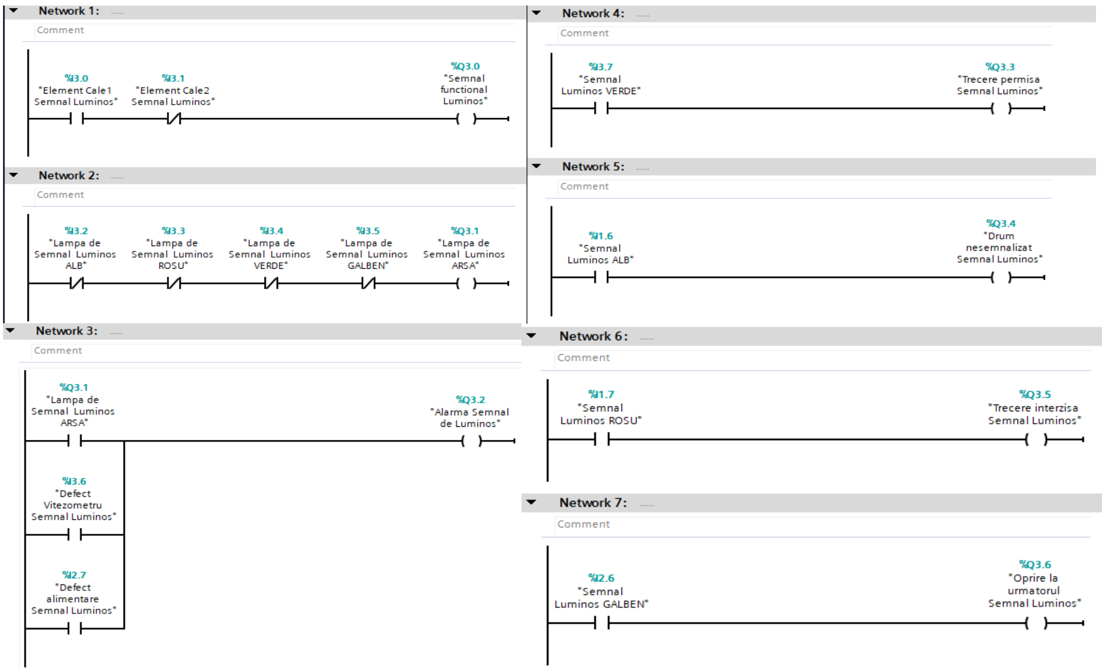

Fig. 2. Ladder diagram for controlling a luminous signal

In line 1: it checks if the conditions for the operation of the maneuvering signal are active, the sensors of the track elements %I3.0, %I3.1. If all conditions are met, the output %Q3.0 is activated and triggers the action "Functional Signal Light".

On line 2: checks the status of the light signal lamps, green, yellow, white, red %I3.2, %I3.3, %I3.4, %I3.5 respectively. If both are burned out, triggers output %Q4.1 "ARSA Light Signal Lamp".

In line 3: monitor the status of the signal lamps and errors that may occur on the signal lamp and thus lead to failure %I3.6, %I2.7, %Q3.1. If both are burned out, output %Q3.2 "Signal Lamp Alarm" shall be triggered.

On line 4: check the status of the green lamp, %I3.7. If it is working in optimal parameters, output %Q3.3 for "Signal Light Pass Allowed" is activated.

In line 5: check the status of the white lamp, %I1.6. If it is operating in optimal parameters, activate output %Q3.3 for "Road not signaled Signal light".

Check the status of the red lamp, %I1.7. If it is working in optimal parameters, activate the output %Q3.4 for "No Passing Signal Light".

In line 7: check the status of the yellow lamp, %I1.6. If it is operating within optimum parameters, activate output %Q3.5 for "Stop at next light signal". Fig. 3 shows the control of a maneuvering signal.

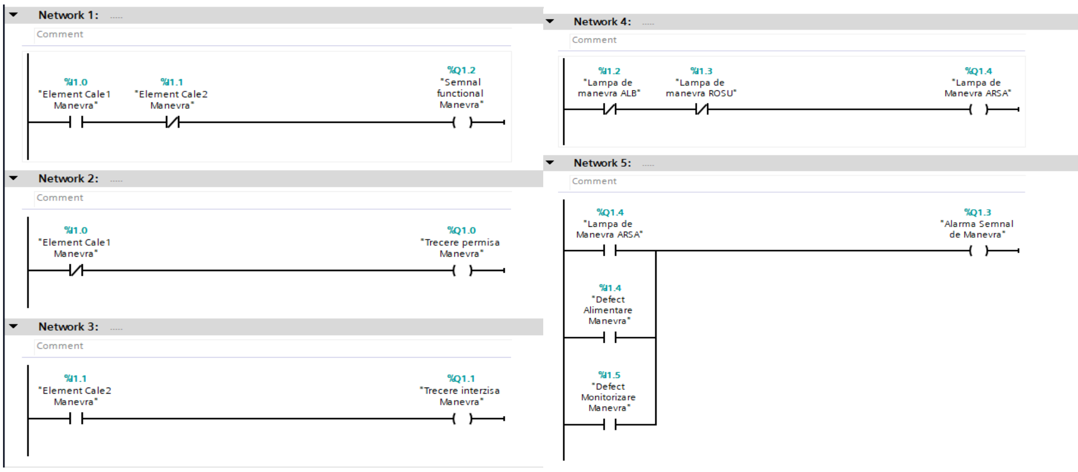

Fig. 3. Ladder diagram for controlling a maneuvering signal

In line 1: check if the conditions for the operation of the maneuvering signal are active, the sensors of the track elements %I1.0, %I1.1. If all conditions are fulfilled, activate the output %Q1.2 and trigger the action "Functional signal Maneuvering".

On line 2: check the track-side element sensor %I1.0. If it is inactive, activate the output %Q1.0 for 'Passing allowed Maneuver'.

In line 3: check the track element sensor %I1.1. If it is inactive, activate the output %Q1.1 for "Passing forbidden Maneuver".

On line 4:check the status of the white and red signal lamps %I1.2, %I1.3 respectively. If both are burned out the output %Q1.4 "Maneuvering Signal Lamp ARSA" is triggered.

In line 5: monitors the status of the signal lamps and errors that may occur on the signal and thus lead to failure %I1.4, %I1.5, %Q1.4. If both are burned out the output %Q1.3 "Shunting Signal Alarm" shall be triggered. Fig. 4 shows the control of the railroad level crossing element.

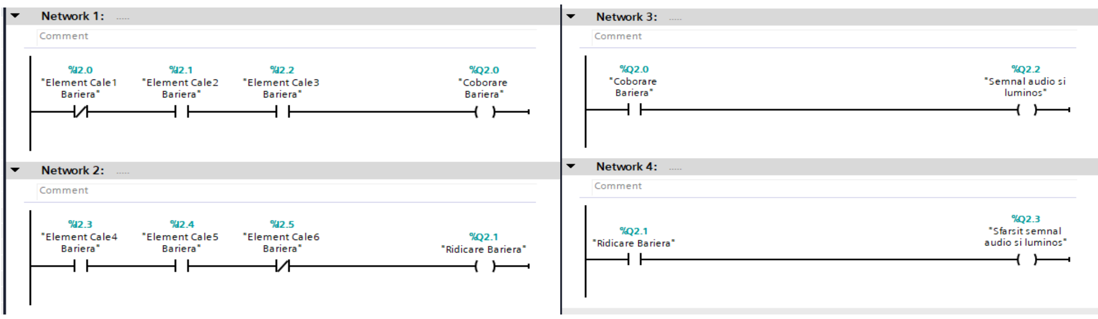

Fig. 4. Ladder diagram for controlling a railway level crossing

In line 1: check whether the conditions for lowering the barrier are active, the status of the track element sensors %I2.0, %I2.1, %I2.2. If all conditions are fulfilled, activate the output %Q2.0 and trigger the action 'Lower Barrier'.

On line 2: the track element sensors %I2.3, %I2.4, %2.5 shall be checked.

In track 3: when the barrier is lowered %Q2.0, an audio and light signal %Q2.2 is also activated, thus warning the traffic participants.

On lane 4: when the barrier is raised %Q2.1, the audio and light signal %Q2.3 is deactivated, indicating the end of the warning process.

To agree with the PLC limitations mentioned in it’s technical book, it is necessary to add an input/output extension module of the type DI 16x24VDC/DQ 16x to use the variables shown and used in the ladder diagrams shown previously.

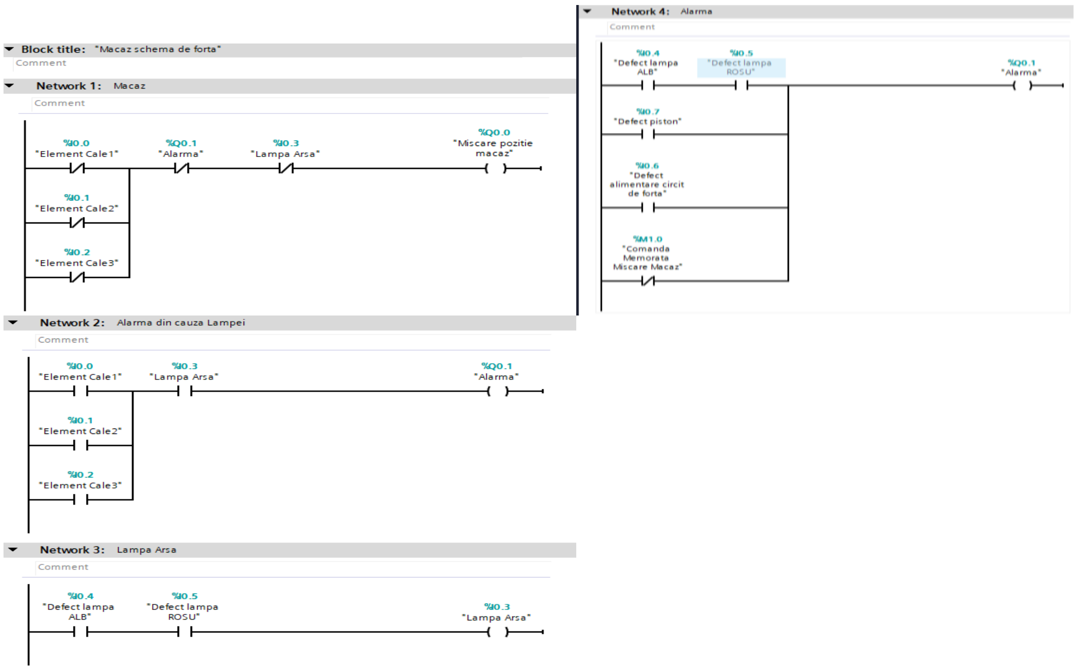

Fig. 5. Point

Fig. 6 shows the HMI interface for the main screen. In it you can see the transitions to move from one screen to another. The following screens used as HMI interfaces are:

- Point;
- Bar Barrier Pass;
- Signal Light1;
- Signal Light2;
- Maneuver Signal;
- System Screens.

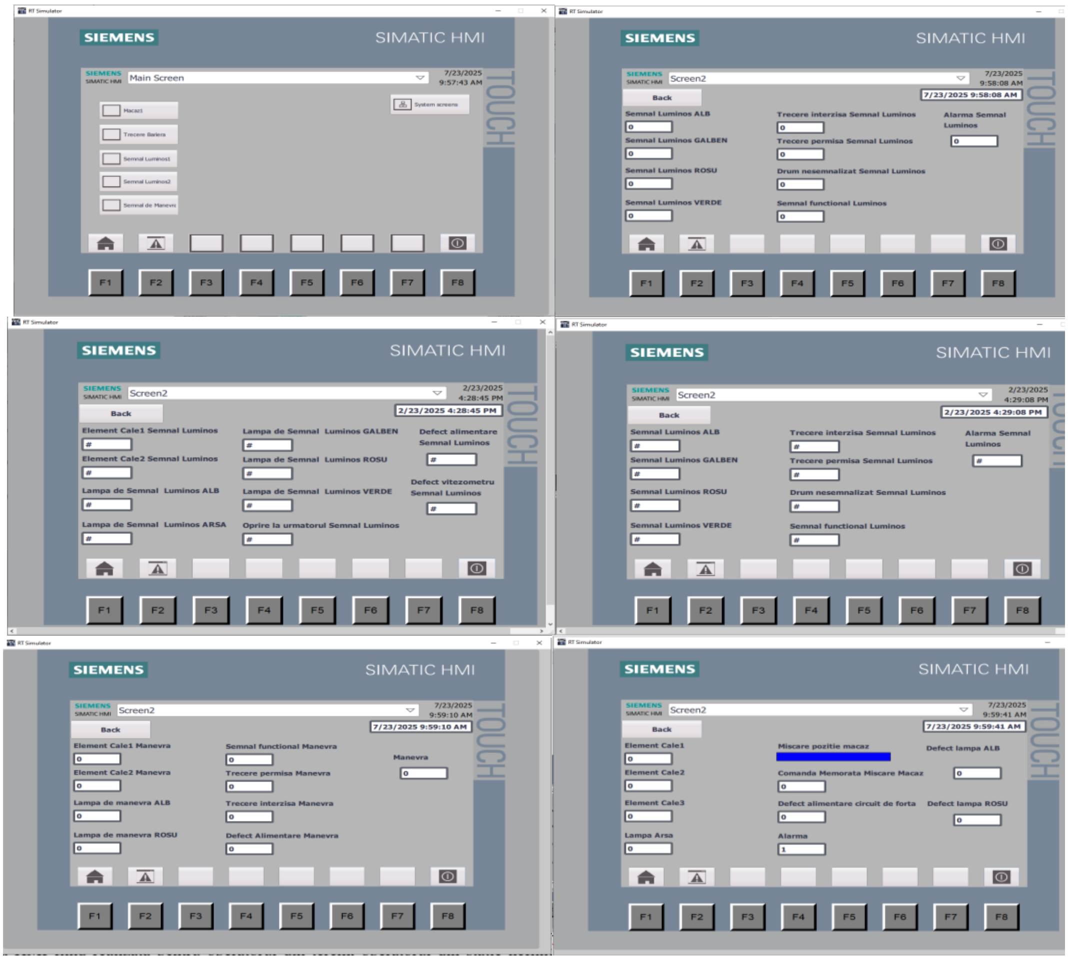

Fig. 6. HMI interface for main screen and railroad grade crossing, Second row: HMI screen interface for luminous signal, Third row: HMI interface for the maneuvering and crane signal

Fig. 6 shows the HMI interfaces for all rail equipment described above. Each HMI interface being realized for the term operator, the station operator not having access to this interface. Fig. 7 shows the representation of the variables used in the ladder diagrams at pin level. It should be noted that all these variables are binary, in order not to use a large number of expansion modules, thus reducing the system costs.

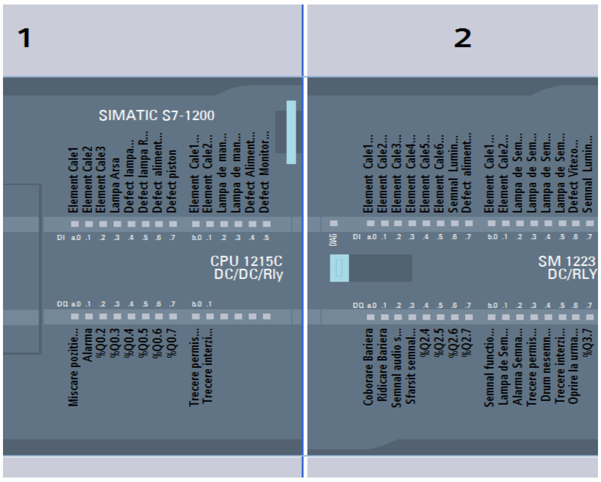

Fig. 7. Presentation of variables at pin level

4. Conclusions

The implementation of a command and control system for rail equipment in a station using PLCs demonstrates efficiency and reliability in the context of rail infrastructure automation. The results obtained highlight a number of key technical and operational benefits, contributing to safety and efficiency in the field [8, 9, 17].

By using PLCs, it facilitated automation, eliminating the need for manual operations that are prone to errors. The implemented system allows precise execution of commands, synchronization of operations and verification of operating parameters, leading to a significant increase in process reliability [1, 5]. The integration of PLCs in the railway system contributes to improving safety by continuously monitoring equipment and implementing mechanisms for protection and rapid intervention in case of dangerous situations that do not occur in a normal way [10, 14, 15, 16].

The command and control system allows real-time detection of faults and automatic activation of safety protocols, thus minimizing the risks associated with the operation of railway infrastructure. By developing a dedicated HMI interface, operators have real-time access to detailed information on equipment status, crane position, rail signaling and level crossing barrier status. The command and control system is essential for quick and efficient intervention in the event of malfunctions or to optimize the operational flow. In addition, the system can record and analyze historical data to facilitate predictive maintenance processes and strategic infrastructure decision-making [18, 19, 20].

A major advantage of using PLCs in this context is the ability to adapt the system to changing requirements. The initially proposed solution can be extended to control a larger number of equipment.

The integration of modern technologies, such as programmable logic controllers (PLCs), distributed sensors, and digital twin solutions, is beginning to be tested in Romania's railway infrastructure, but their application remains fragmented and limited to isolated projects.

In contrast, railway networks in Western Europe and Asia already benefit from developed architectures, where these systems are operational and contribute significantly to the automation and optimization of critical processes. Given the positive results obtained in the stations currently undergoing modernization, we believe that extending these technologies to adjacent lines is a feasible and necessary step towards increasing the resilience and efficiency of the national railway system.

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