МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Факультет аеронавігації, електроніки та телекомунікацій

Кафедра авіаційних комп’ютерно-інтегрованих комплексів

ДОПУСТИТИ ДО ЗАХИСТУ

Завідувач випускової кафедри

_________ В. М. Синєглазов

«___» ______________ 2023р.

КВАЛІФІКАЦІЙНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬО-КВАЛІФІКАЦІЙНОГО РІВНЯ “БАКАЛАВР”

Спеціальність 151 «Автоматизація та комп'ютерно-інтегровані технології»

Освітньо-професійна програма «Комп’ютерно-інтегровані технологічні процеси і виробництва»

Тема: Автоматизована система керування виробничою лінією з використанням програмованих логічних контролерів

Виконавець: студент групи ФАЕТ-404 Карацюпа Владислав Богданович

Керівник: кандидат технічних наук, Сергеєв Ігор

Нормоконтролер: _________ Філяшкін М. К.

(підпис)

Київ 2023

EDUCATION AND SCIENCE MINISTRY OF UKRAINE

NATIONAL AVIATION UNIVERSITY

Faculty of Aeronavigation, Electronics and Telecommunications

Department of computer integrated complexes

ADMIT TO DEFENSE

Head of the graduate department

_______ Viktor M. Sineglazov

«___» ______________ 2023

QUALIFICATION WORK

(EXPLANATORY NOTE)

GRADUATE OF EDUCATION AND QUALIFICATION LEVEL

"BACHELOR"

Specialty 151 "Automation and computer-integrated technologies"

Educational and professional program "Computer-integrated technological processes and production"

Theme: Automated system of production line management with usage of programmable logic controllers

Performer: student of group FAET-404 Karatsuipa Vladyslav Bogdanovich

Supervisor: Candidate of Technical Sciences, Igor Sergeyev

Normocontroller: ________ Filyashkin M. K.

(signature)

Kyiv 2023

NATIONAL AVIATION UNIVERSITY

Faculty of aeronavigation, electronics and telecommunications

Department of Aviation Computer Integrated Complexes

Educational level: bachelor

Specialty: 151 "Automation and computer-integrated technologies"

APPROVED

Head of Department

Sineglazov V. M.

«____» __________2023

TASK

For the student's thesis

Karatsuipa Vladyslav Bogdanovich

1. Theme of project: "Automated system of production line management with usage of programmable logic controllers".
2. The term of the project: from May 10, 2023, until June 7, 2023
3. Output data to the project: description of the production line, requirements for the control system, selection of a programmable logic controller, system design, software development, and connection of sensors and actuators.
4. Contents of the explanatory note: 1. Analysis of modern production process automation technologies: review of existing production line control systems.2. Design of the control system: selection of the optimal system architecture.3. Implementation of the control system: selection and programming of a programmable logic controller, development of software for the control system.
5. List of required illustrative material: tables, figures, diagrams, graphs.
6. Planned schedule.

№	Task	Execution term	Execution mark
1.	Getting the task	01.04.2023 – 02.04.2023	Done

2.	Formation of the purpose and main objectives of the study	02.04.2023 – 14.04.2023	Done
3.	Analysis of existing methods	15.04.2023 – 30.04.2023	Done
4.	Theoretical consideration of problem solving	01.05.2023 – 05.05.2023	Done
5.	Software implementation of the automation program of the production line control system	06.05.2023 – 25.05.2023	Done
6.	Preparation of an explanatory note	26.05.2023 – 03.06.2023	Done
7.	Preparation of presentation and handouts	04.06.2023 – 06.06.2023	Done

7. Date of task receiving: «___» ________ 2023.

Diploma thesis supervisor _____________ Sergeyev Igor

(signature)

Issued task accepted _____________ Karatsuipa Vladyslav

(signature)

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Факультет аеронавігації, електроніки та телекомунікацій

Кафедра авіаційних комп’ютерно-інтегрованих комплексів

Освітній ступінь: Бакалавр

Спеціальність: 151 «Автоматизація та комп'ютерно-інтегровані технології»

ЗАТВЕРЖДУЮ

Завідувач кафедри

Синєглазов В. М.

«___» __________2023

ЗАВДАННЯ

На виконання дипломної роботи

Карацюпи Владислава Богдановича

1. Тема проекту: «Автоматизована система керування виробничою лінією з використанням програмованих логічних контролерів».
2. Термін виконання роботи: з 10.05.2023р. по 07.06.2023р.
3. Вихідні дані роботи: опис виробничої лінії, вимоги до системи керування, вибір програмованого логічного контролера, проектування системи, розробка програмного забезпечення та підключення сенсорів та виконавчих механізмів.
4. Зміст пояснювальної записки:1.Аналіз сучасних технологій автоматизації виробничих процесів:огляд існуючих систем керування виробничими лініями.2.Проектування системи керування:вибір оптимальної архітектури системи.3.Реалізація системи керування:вибір та програмування програмованого логічного контролера,розробка програмного забезпечення для системи керування.
5. Перелік обов’язкового графічного матеріалу: таблиці, рисунки, діаграми, графіки.
6. Календарний план-графік.

№	Завдання	Термін виконання	Підпис керівника
1.	Отримання завдання	01.04.2023 – 02.04.2023	Виконано
2.	Формування мети та основних завдань дослідження	02.04.2023 – 14.04.2023	Виконано
3.	Аналіз існуючих методів	15.04.2023 – 30.04.2023	Виконано
4.	Теоретичний розгляд рішення задач	01.05.2023 – 05.05.2023	Виконано
5.	Програмна реалізація програми автоматизації системи управління виробничою лінією	06.05.2023 – 25.05.2023	Виконано
6.	Оформлення пояснювальної записки	26.05.2023 – 03.06.2023	Виконано
7.	Підготовка презентації та роздаткового матеріалу	04.06.2023 – 06.06.2023	Виконано

7. Дата видачі завдання: «__» _______ 2023р.

Керівник дипломної роботи (проекту): _____________ Сергеєв Ігор

(підпис)

Завдання прийняв до виконання: _____________ Карацюпа Владислав

(підпис)

ABSTRACT

Explanatory note of the qualification work " Automated system of production line management with usage of programmable logic controllers " 52 p., 15 figs., 1 tables, 7 sources.

Modern manufacturing processes are becoming more complex and diverse, requiring efficient and precise control to achieve high productivity and quality. Automation is a crucial factor in ensuring the optimal functioning of production lines, allowing businesses to achieve a competitive advantage in the market.

One of the most important components of production process automation is the use of programmable logic controllers (PLCs). PLCs are specialized electronic devices designed to control and monitor automated systems. They provide fast and reliable execution of programs that control the operation of production lines, monitor the status of equipment, control parameters, and respond to changes in production processes.

The purpose of this thesis is to develop and implement an automated production line control system using programmable logic controllers. The main focus is on determining the optimal system architecture, programming the PLC, connecting sensors and actuators, as well as testing and debugging the system. The result of the work will be an efficient and reliable automated control system that ensures optimal productivity and production quality.

The importance of this thesis lies in solving urgent problems of automation of production processes and implementation of modern management technologies at the enterprise. Automation of production lines using PLCs can increase productivity, reduce labor costs, minimize errors, and provide more precise control over production processes. This has a significant impact on the competitiveness of the enterprise and its ability to meet market demands.

This work includes analysis of the production process, selection of the optimal programmable logic controller, control system design, software development, connection of sensors and actuators, testing and debugging of the system, and implementation and support of the system. The results of this work are expected to

improve the efficiency and productivity of the production line, as well as help solve a number of problems that arise in the production process.

The following discussion will describe in detail the steps and stages of implementing an automated production line control system using programmable logic controllers. This work is important for the further development of production automation and the introduction of modern management technologies at enterprises of various sizes.

РЕФЕРАТ

Пояснювальна записка кваліфікаційної роботи «Автоматизована система керування виробничою лінією з використанням програмованих логічних контролерів» 52 с., 15 рис., 1 табл, 7 джерел.

Сучасні виробничі процеси стають все складнішими та розмаїтішими, вимагаючи ефективного та точного управління для досягнення високої продуктивності та якості. Автоматизація є вирішальним фактором у забезпеченні оптимального функціонування виробничих ліній, що дозволяє підприємствам досягати конкурентної переваги на ринку.

Одним із найважливіших компонентів автоматизації виробничих процесів є використання програмованих логічних контролерів (ПЛК). ПЛК є спеціалізованими електронними пристроями, призначеними для керування та контролю автоматизованими системами. Вони забезпечують швидке та надійне виконання програм, які керують роботою виробничих ліній, відстежують стан обладнання, здійснюють контроль параметрів та реагують на зміни у виробничих процесах.

Метою даної дипломної роботи є розробка та реалізація автоматизованої системи керування виробничою лінією з використанням програмованих логічних контролерів. Основна увага приділяється визначенню оптимальної архітектури системи, програмуванню ПЛК, підключенню сенсорів та виконавчих механізмів, а також тестуванню та налагодженню системи. Результатом роботи буде створення ефективної та надійної автоматизованої системи керування, яка забезпечує оптимальну продуктивність та якість виробництва.

Важливість даної дипломної роботи полягає у вирішенні актуальних проблем автоматизації виробничих процесів та упровадженні сучасних технологій управління на підприємстві. Автоматизація виробничих ліній з використанням ПЛК дозволяє підвищити продуктивність, знизити витрати на робочу силу, мінімізувати помилки та забезпечити більш точний контроль над процесами виробництва. Це має суттєвий вплив на конкурентоспроможність підприємства та його здатність задовольняти вимоги ринку.

Дана робота включає аналіз виробничого процесу, вибір оптимального програмованого логічного контролера, проектування системи керування, розробку програмного забезпечення, підключення сенсорів та виконавчих механізмів, тестування та налагодження системи, а також впровадження та підтримку системи. Очікується, що результати даної роботи сприятимуть покращенню ефективності та продуктивності виробничої лінії, а також допоможуть вирішити ряд проблем, що виникають у процесі виробництва.

В подальшому розгляді будуть детально описані кроки та етапи реалізації автоматизованої системи керування виробничою лінією з використанням програмованих логічних контролерів. Дана робота має важливе значення для подальшого розвитку автоматизації виробництва та впровадження сучасних технологій управління на підприємствах різного масштабу.

CONTENT

GLOSSARY

PLC – Programmable Logic Controller

CPU – Central Processing Unit

HMI – Human-Machine Interface

FBD – Function Block Diagrams

SFC – Sequential Function Charts

1. INTRODUCTION

As the global manufacturing sector continually seeks to improve efficiency and productivity while reducing costs, the implementation of automated production line management has emerged as a significant trend. This shift towards automation is primarily driven by advancements in technology, including robotics, machine learning, artificial intelligence, and the Internet of Things (IoT).

Automated production line management involves the use of automated machinery and control systems to manage and control production processes with minimal human intervention. This includes everything from the assembly and processing of products to their inspection, testing, and packaging.

The benefits of automated production line management are numerous. It can lead to increased productivity due to the ability of machines to operate continuously without breaks. It also enhances precision and consistency, minimizing human error and variance in product quality. Furthermore, it can improve safety by reducing the need for human workers to perform dangerous or physically demanding tasks.

However, despite its advantages, the shift towards automation also brings challenges. These include the high initial costs of setting up automated systems, the need for skilled personnel to operate and maintain these systems, and potential job displacement due to automation.

This topic is of particular importance given the rapid pace of technological advancement and the increasing pressure on manufacturers to compete on a global scale. Understanding the implications of automated production line management, both positive and negative, is crucial for businesses, policymakers, and workers alike. In this light, our study aims to delve deeper into the nuances of automated production line management and its impact on the manufacturing landscape.

Automated production line control systems play a crucial role in modern manufacturing processes. These systems utilize programmable logic controllers (PLCs) to automate and control various aspects of the production line, resulting in increased efficiency, accuracy, and productivity. In this introduction, we will explore the key concepts and components of an automated production line control system using PLCs.

A programmable logic controller (PLC) is a specialized industrial computer that is designed to control and monitor machinery and processes on a production line. PLCs are commonly used in manufacturing environments due to their reliability, robustness, and flexibility. They can be programmed to perform specific tasks and execute complex logic functions based on input signals from sensors and other devices.

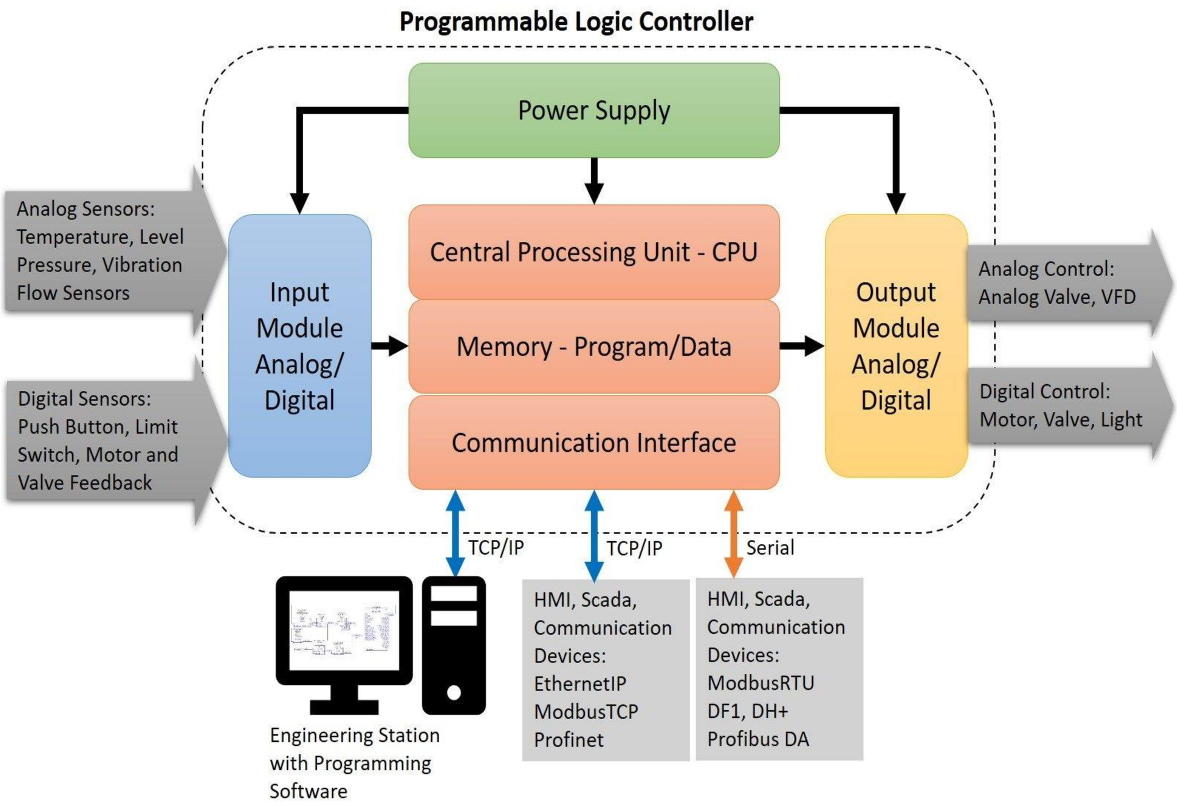

Figure 1. PLC Architecture

The main objective of an automated production line control system is to coordinate and synchronize the operation of different machines, equipment, and processes involved in the production line. By employing PLCs, manufacturers can achieve precise control over the timing, sequencing, and coordination of operations, resulting in optimized production flow.

The key components of an automated production line control system using PLCs include:

1. Programmable Logic Controllers (PLCs): These are the central control devices responsible for executing the control logic and coordinating the operation of various components in the production line.
2. Input/Output (I/O) Modules: These modules interface with sensors and actuators in the production line, converting analog or digital signals into a format that can be processed by the PLC. They provide the means for the PLC to receive information from the field and send commands to the devices.
3. Sensors: Sensors are used to detect and measure various parameters such as temperature, pressure, position, speed, and presence of objects. They provide real-time feedback to the PLC, allowing it to make decisions and adjust the production process accordingly.
4. Actuators: Actuators are devices responsible for physically controlling the operation of machinery and equipment. They receive commands from the PLC and execute actions such as starting/stopping motors, opening/closing valves, and moving robotic arms.
5. Human-Machine Interface (HMI): The HMI is the user interface that allows operators and technicians to interact with the automated control system. It provides a visual representation of the production line, real-time data monitoring, and the ability to change parameters and settings.
6. Communication Networks: These networks facilitate data exchange between the PLCs, I/O modules, sensors, actuators, and other components of the control system. They enable real-time monitoring, diagnostics, and control over the entire production line.

The programming of a PLC involves creating a control program using specialized software. The program defines the logic and behavior of the automated production line, including sequences, timers, interlocks, and error handling. The PLC continuously scans the program, reads input signals, executes the control logic, and updates the output signals accordingly.

Automated production line control systems using PLCs offer numerous advantages, such as increased productivity, improved product quality, reduced downtime, and enhanced safety. They enable manufacturers to streamline operations, adapt to changing production requirements, and achieve higher levels of efficiency and profitability.

1.1. Background of the study

For a study on automated production line management, the background might look something like this:

Introduction to Automated Production Lines: Explain the concept of automation in production and its significance in modern industries. This could include a brief history of production line management, leading to the current trend of automation, as well as the rationale behind this trend (e.g., increased efficiency, cost reduction, improved product consistency).

Current State of Knowledge: Discuss what previous research has found about automated production line management. This could include benefits that have been identified, as well as drawbacks or challenges. Mention different sectors where automation has been implemented and the results achieved.

The Gap in Existing Research: Identify areas where more research is needed. For example, perhaps there's a lack of research on how automation affects small and medium enterprises (SMEs), or maybe there's little understanding of how employees perceive automation or what sort of training is required to help them adapt.

Significance of Your Study: Explain how your study will contribute to the existing body of knowledge. For example, if your study is focusing on SMEs, discuss why it's important to understand the impact of automation on these businesses.

Research Questions or Objectives: Finally, present the specific questions or objectives that your study will address. These should be directly related to the gaps in knowledge that you identified earlier.

Remember, the purpose of the background of the study is to set up the context for your research and demonstrate the need for it. It should provide the information that a reader needs to understand why your research questions or objectives are important.

The background of the study on automated production line control systems using PLCs includes the historical development of PLC technology. PLCs were initially introduced in the late 1960s as a replacement for hardwired relay systems. They quickly gained popularity due to their versatility and ease of programming.

Over the years, PLCs evolved and became more powerful, offering advanced features and capabilities. They became capable of handling complex logic functions, communicating over industrial networks, and integrating with other control systems. This evolution allowed PLCs to be widely adopted in various industries such as automotive, electronics, food and beverage, pharmaceuticals, and many more.

The study of automated production line control systems using PLCs focuses on understanding the principles, design considerations, and implementation strategies of such systems. It involves examining the hardware and software components of a control system, including PLCs, I/O modules, sensors, actuators, and communication networks.

Researchers and engineers explore different programming languages, methodologies, and best practices for developing efficient and reliable control programs for PLCs. They investigate topics such as ladder logic, function block diagrams, structured text, and sequential function charts, which are commonly used for PLC programming.

Additionally, the study may encompass topics related to system integration, human-machine interfaces (HMIs), fault diagnosis, maintenance strategies, and optimization techniques. Researchers aim to improve the performance, reliability, and safety of automated production line control systems through innovative approaches and technological advancements.

Overall, the background of the study on automated production line control systems using PLCs arises from the continuous drive to enhance manufacturing processes, increase efficiency, and achieve higher levels of productivity in industrial settings.

1.2. The problem statement

The problem statement for the study of automated production line control systems using programmable logic controllers (PLCs) can be framed as follows:

In modern manufacturing industries, there is a growing need for efficient and reliable control systems to optimize production line processes. While PLCs have been widely adopted for automating production lines, there are still challenges and issues that need to be addressed.

1. Inefficient Production Flow: Many production lines suffer from inefficient flow due to inadequate coordination and synchronization between machines and processes. This can result in bottlenecks, idle time, and reduced overall productivity. There is a need to develop control systems that can optimize the production flow by effectively coordinating and sequencing operations.
2. Lack of Flexibility: Traditional control systems often lack the flexibility to adapt to changing production requirements. This can be a significant limitation when manufacturers need to introduce new products, modify production sequences, or accommodate variations in demand. A flexible control system is needed to easily reconfigure the production line and accommodate changes without significant downtime.
3. Limited Fault Diagnosis and Maintenance: Timely detection and diagnosis of faults in the production line are crucial for minimizing downtime and ensuring smooth operations. However, existing control systems may have limited fault diagnostic capabilities, making it challenging to identify and resolve issues quickly. A comprehensive and intelligent fault diagnosis system is needed to enhance maintenance strategies and reduce downtime.
4. Complex Programming and Integration: PLC programming for automated production line control systems can be complex and time-consuming. Additionally, integrating different components, such as sensors, actuators, and HMIs, into a cohesive control system can present integration challenges.

Simplifying programming methods and improving integration techniques are essential to streamline system development and deployment.

5. Safety and Risk Mitigation: Safety is a critical aspect of production line control systems. Ensuring the safety of operators and the equipment requires robust safety protocols and fail-safe mechanisms. There is a need to develop control systems that incorporate advanced safety features and risk mitigation strategies to prevent accidents and minimize potential hazards.

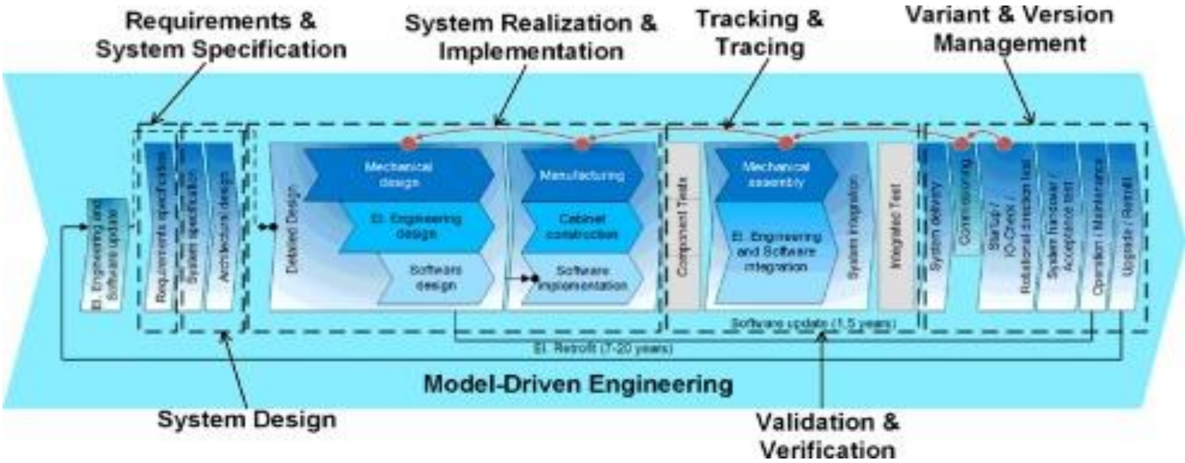

Figure 2. Evolution of software in automated production systems

The objective of the study is to address these challenges and develop innovative solutions for automated production line control systems using PLCs. By doing so, the study aims to enhance production line efficiency, flexibility, fault diagnosis capabilities, ease of programming, and overall safety in manufacturing industries.

1.3. Objectives of the study

The objectives of the study on automated production line control systems using programmable logic controllers (PLCs) are as follows:

1. Develop an optimized control system: The study aims to design and implement an automated production line control system that optimizes the production flow, minimizes bottlenecks, and maximizes overall productivity. This involves coordinating and synchronizing the operation of machines and processes to ensure efficient and smooth production.

2. Enhance flexibility and adaptability: The study seeks to improve the flexibility of the control system to accommodate changes in production requirements. This includes developing methods to easily reconfigure the production line, modify production sequences, and adapt to variations in product demand without significant downtime or disruption.
3. Implement intelligent fault diagnosis: The study aims to incorporate intelligent fault diagnosis techniques into the control system. By utilizing advanced algorithms and data analysis methods, the system can quickly detect, diagnose, and resolve faults in the production line. This improves maintenance strategies, reduces downtime, and enhances overall system reliability.
4. Simplify programming methods: The study focuses on simplifying the programming process for PLCs in automated production line control systems. This involves exploring user-friendly programming languages, methodologies, and tools that enable efficient development and maintenance of control programs. The objective is to streamline the programming process and reduce complexity.
5. Improve integration capabilities: The study aims to enhance the integration of various components in the control system, including sensors, actuators, and human-machine interfaces (HMIs). By developing efficient communication protocols and integration techniques, the study aims to ensure seamless data exchange and interoperability between different system components.
6. Enhance safety features and risk mitigation: Safety is a crucial aspect of production line control systems. The study focuses on incorporating advanced safety features and risk mitigation strategies into the control system. This includes implementing fail-safe mechanisms, safety protocols, and real-time monitoring to prevent accidents, protect operators, and minimize potential hazards.
7. Evaluate performance and assess benefits: The study aims to evaluate the performance of the developed control system by conducting thorough testing and analysis. This involves measuring key performance indicators such as productivity, efficiency, downtime, and error rates. The objective is to assess the

benefits and effectiveness of the control system and identify areas for further improvement.

By achieving these objectives, the study aims to contribute to the advancement of automated production line control systems using PLCs, leading to increased efficiency, flexibility, fault diagnosis capabilities, ease of programming, and overall safety in manufacturing industries.

1.4. Scope and limitations of the study

The scope of the study on automated production line control systems using programmable logic controllers (PLCs) encompasses the following aspects:

1. Control System Design: The study focuses on the design and implementation of an automated production line control system using PLCs. It includes the selection and integration of PLCs, I/O modules, sensors, actuators, and communication networks to create a cohesive control system.
2. Programming Methods: The study explores various programming languages and methodologies for PLC programming, with a focus on developing efficient and reliable control programs for the production line. It aims to simplify programming methods to streamline the development and maintenance of control programs.
3. Integration and Communication: The study covers the integration of different components in the control system, including sensors, actuators, and human-machine interfaces (HMIs). It addresses communication protocols and techniques to enable seamless data exchange and interoperability between system components.
4. Fault Diagnosis and Maintenance: The study includes the incorporation of intelligent fault diagnosis techniques into the control system. It aims to develop methods for quick detection, diagnosis, and resolution of faults in the production line, enhancing maintenance strategies and minimizing downtime.
5. Flexibility and Adaptability: The study focuses on enhancing the flexibility and adaptability of the control system to accommodate changes in production

requirements. It explores methods for easily reconfiguring the production line, modifying production sequences, and adapting to variations in demand.

6. Safety Features: The study addresses safety considerations in the control system design, including the implementation of advanced safety features, fail-safe mechanisms, and risk mitigation strategies. It aims to enhance the safety of operators and minimize potential hazards in the production line.

However, there are certain limitations to the study:

1. Specific Industries: The study's scope may be limited to specific industries or manufacturing processes. Different industries may have unique requirements and specific control system configurations, which may not be fully covered in the study.
2. Hardware and Software Constraints: The study may not extensively cover all available hardware and software options for PLCs and other components. It may focus on specific platforms, models, or software tools based on the researcher's expertise and availability.
3. Implementation Challenges: The study may not delve deeply into the challenges and constraints faced during the actual implementation of the control system. Factors such as budget constraints, physical space limitations, and compatibility issues with existing infrastructure may not be fully explored.
4. Performance Evaluation: While the study aims to evaluate the performance of the developed control system, the scope may not cover an exhaustive analysis of all possible performance metrics. It may focus on a subset of metrics deemed most relevant to the study objectives.
5. Economic Factors: The study may not extensively address economic considerations, such as the cost-effectiveness of implementing the control system or the return on investment. These factors are highly dependent on the specific industry, production volume, and market conditions.

It is important for researchers and practitioners to acknowledge these limitations and adapt the findings and recommendations of the study to their specific contexts and requirements.

2. LITERATURE REVIEW

2.1. Overview of automation and production line management

Automation and production line management are essential components of modern industrial operations. They involve the integration of technology, processes, and systems to optimize manufacturing efficiency, productivity, and quality. Here's an overview of automation and production line management:

1. Automation:

- Automation refers to the use of technology and machinery to perform tasks with minimal human intervention. It aims to improve efficiency, reduce errors, and enhance overall productivity. Automation can be applied at various levels, including individual machines, workstations, and entire production lines. Some key aspects of automation include:
- Robotic Automation: The use of robots to perform repetitive or complex tasks. Industrial robots can handle assembly, welding, material handling, and other manufacturing processes.
- Machine Automation: The automation of individual machines or equipment using control systems such as programmable logic controllers (PLCs). This enables precise control, monitoring, and synchronization of machine operations.
- Process Automation: Automation of complete manufacturing processes by integrating multiple machines, equipment, and systems. It involves the coordination of various steps and the seamless flow of materials and information.

2. Production Line Management:

- Production line management focuses on the planning, organization, and control of production processes to achieve efficient and effective operations. It involves managing resources, workflows, and schedules to ensure the timely and cost-effective production of goods. Key aspects of production line management include:

- Production Planning: Determining the production volume, schedules, and resource allocation to meet customer demand. It involves forecasting, capacity planning, and sequencing of operations.
- Material Management: Managing the flow of materials, including procurement, inventory control, and logistics. Effective material management ensures the availability of required components and minimizes waste.
- Quality Control: Implementing quality assurance measures to ensure products meet specified standards. This involves quality inspections, testing, and continuous improvement initiatives.
- Maintenance and Upkeep: Managing equipment maintenance, repair, and preventive maintenance activities to minimize downtime and optimize equipment performance.
- Workforce Management: Ensuring proper staffing, training, and supervision of workers. It includes defining roles, responsibilities, and performance metrics to achieve production targets.

Figure 3. Production line automation

Automation and production line management work hand in hand to optimize manufacturing operations. Automation technologies enable increased efficiency, accuracy, and flexibility, while production line management provides the framework for effective planning, coordination, and control of production processes. Together, they contribute to improved productivity, reduced costs, enhanced product quality, and increased competitiveness in today's manufacturing landscape.

2.2. Advantages and disadvantages of automated production line management

Automated production line management offers numerous advantages for manufacturing operations. Here are some key benefits:

- Increased Productivity: Automation streamlines production processes, eliminates manual tasks, and reduces human error. It leads to higher production rates and improved overall productivity. Automated systems can operate continuously, without the need for breaks or shift changes, resulting in uninterrupted production.
- Improved Efficiency: Automated production line management optimizes resource utilization, minimizes downtime, and reduces waste. It enables efficient scheduling, sequencing, and coordination of operations, ensuring smooth material flow and eliminating bottlenecks. This results in improved operational efficiency and reduced cycle times.
- Enhanced Quality Control: Automation enables consistent and standardized production processes, reducing variations and errors. It allows for precise control and monitoring of critical parameters, ensuring consistent product quality. Automated systems can perform real-time quality inspections, identify defects, and implement corrective measures promptly.
- Flexibility and Adaptability: Automated production line management facilitates quick reconfiguration and adaptation to changing production requirements. It allows for easy adjustment of production volumes, product variations, and sequencing. This flexibility helps manufacturers respond to market demands, introduce new products, or accommodate customization requests.
- Safety and Risk Mitigation: Automation reduces the reliance on manual labor for repetitive or hazardous tasks, improving worker safety. Automated systems can be equipped with safety features, such as sensors and emergency stop

mechanisms, to prevent accidents. It minimizes the risk of injuries and creates a safer work environment.

- Data-driven Decision Making: Automated production line management generates vast amounts of real-time data on production metrics, equipment performance, and quality parameters. This data can be analyzed to identify trends, optimize processes, and make informed decisions. Data-driven insights enable continuous improvement and operational excellence.
- Cost Savings: Although the initial investment in automation can be significant, it offers long-term cost savings. Automation reduces labor costs, lowers scrap and rework expenses, and optimizes resource utilization. It also minimizes energy consumption and reduces the need for manual inspections and rework.
- Scalability and Expansion: Automated production line management allows for scalability and expansion of manufacturing operations. Additional equipment or processes can be easily integrated into the existing system, accommodating growth and increasing production capacity. It offers a modular approach, enabling gradual expansions as needed.

While automated production line management brings numerous advantages, it's important to also consider the potential disadvantages:

High Initial Investment: The cost of purchasing, implementing, and maintaining automated machinery can be high, especially for small and medium enterprises (SMEs). Initial costs include machinery purchase, installation, and system integration. Ongoing costs include system maintenance and upgrades.

Technical Challenges: Implementing automated systems requires a certain level of technical expertise. Additionally, in case of breakdowns or malfunctions, specialized knowledge is needed to diagnose and repair the problems, which can result in production downtime.

Job Displacement: Automation can lead to job losses, particularly for roles involving routine or repetitive tasks. This can have social and economic implications. On the other hand, it can also lead to creation of new jobs requiring different skill sets.

Lack of Flexibility: Automated production lines can be less flexible than human-operated ones. They are typically designed for high-volume, standardized production, and may not be suitable for making customized products or for easily switching between different types of products.

Dependence on Power Supply: Automated systems are heavily reliant on a continuous power supply. Any interruption in power can bring the production line to a halt, resulting in lost time and productivity.

Cybersecurity Risks: With increased automation and connectivity (Industry 4.0) comes increased exposure to cyber threats. Companies need to invest in appropriate security measures to protect their systems and data.

Obsolete Equipment: Technology evolves rapidly, and today's cutting-edge system can become outdated in a few years. Companies need to plan for future upgrades and replacements.

Despite these potential drawbacks, many businesses find that the benefits of automation outweigh the challenges, particularly in the long run. The key is to plan and implement automation strategies carefully, considering both the immediate and long-term implications.

Overall, automated production line management revolutionizes manufacturing operations by increasing productivity, improving efficiency, ensuring consistent quality, and providing flexibility. It enhances safety, enables data-driven decision making, and offers long-term cost savings. These advantages make it a crucial element for modern manufacturing industries seeking to stay competitive and meet evolving market demands.

2.3. Review of related studies and systems

Studies on Production Line Optimization: Numerous studies have focused on optimizing production lines through the use of PLC-based control systems. These studies often propose algorithms and methodologies to improve production flow, reduce bottlenecks, and enhance overall efficiency. They explore techniques such as production scheduling, sequencing, and real-time monitoring to achieve optimal performance.

Research on PLC Programming and Control: Several studies delve into the programming and control aspects of PLCs in automated production lines. They explore different programming languages, methodologies, and software tools to develop efficient and reliable control programs. The emphasis is on streamlining programming techniques, reducing complexity, and enhancing the flexibility of PLC-based control systems.

Intelligent Fault Diagnosis and Maintenance: The development of intelligent fault diagnosis systems for automated production lines using PLCs is a significant area of research. These studies utilize advanced algorithms, data analysis techniques, and machine learning methods to detect, diagnose, and resolve faults in real-time. The objective is to minimize downtime, enhance maintenance strategies, and improve overall system reliability.

Integration of Sensors and Actuators: Research in this area focuses on the integration of various sensors and actuators into automated production line control systems. These studies explore communication protocols, data exchange methods, and hardware integration techniques to ensure seamless interoperability between different components. The aim is to create a cohesive system that can efficiently monitor and control the production processes.

Safety Systems and Risk Mitigation: Many studies emphasize the incorporation of advanced safety systems and risk mitigation strategies in automated production line control systems. These systems integrate safety protocols, emergency stop mechanisms, and safety monitoring features to ensure operator safety and prevent accidents. The focus is on implementing fail-safe mechanisms and real-time risk assessment methods.

Case Studies and Industry Applications: Numerous research studies present case studies and practical applications of automated production line control systems using PLCs in various industries. These studies highlight successful implementations, challenges faced, and lessons learned from real-world scenarios. They provide insights into the benefits, limitations, and best practices for deploying such systems in different manufacturing contexts.

Overall, the research in the field of automated production line control systems using PLCs encompasses a wide range of topics, including optimization, programming, fault diagnosis, integration, safety, and real-world applications. The studies aim to enhance production efficiency, flexibility, fault detection, and overall system performance. They contribute to the ongoing advancement and innovation in manufacturing industries, enabling more efficient and reliable production processes.

2.4. Programmable logic controllers (PLCs) and their use in automation

Programmable logic controllers (PLCs) are specialized digital computers used in industrial automation to control and monitor various processes and machinery. They play a crucial role in automating manufacturing, assembly lines, and other industrial applications. Here is an overview of PLCs and their use in automation:

- Basic Functionality: PLCs are designed to perform real-time control of industrial processes. They receive input signals from sensors, process the data, and generate output signals to control actuators and other devices. PLCs can execute logic functions, timers, counters, arithmetic operations, and communication protocols, allowing for complex control algorithms.
- Programming and Configuration: PLCs are programmable devices, which means their behavior can be customized to suit specific applications. Programming languages like ladder logic, function block diagrams (FBD), structured text (ST), and others are used to develop control programs for PLCs. These programs define the behavior and logic of the control system.
- Inputs and Outputs: PLCs interface with the physical world through input and output (I/O) modules. Inputs receive signals from sensors or other devices, such as limit switches, temperature sensors, or level sensors. Outputs send signals to actuators, such as motors, solenoids, or valves, to control machinery or processes. PLCs support various types of digital and analog I/O modules.
- Communication and Networking: PLCs can communicate with other devices and systems through communication protocols such as Modbus, Profibus, Ethernet/IP,

and others. This enables data exchange between PLCs, human-machine interfaces (HMIs), supervisory control and data acquisition (SCADA) systems, and higher-level enterprise systems. PLCs can also communicate with remote I/O devices or field devices using remote I/O protocols.

- Real-Time Control and Determinism: PLCs offer real-time control capabilities, ensuring precise and deterministic operation of industrial processes. They execute control tasks in predictable time intervals, allowing for synchronized control of multiple devices or processes. This is crucial for applications that require precise timing or coordination, such as synchronized motion control.
- Flexibility and Scalability: PLC-based automation systems offer flexibility and scalability. They can be easily reprogrammed and reconfigured to accommodate changes in the production process or to introduce new products. Additional I/O modules, communication interfaces, or expansion racks can be added to expand the system's capabilities.
- Reliability and Robustness: PLCs are designed to withstand harsh industrial environments. They are built to be durable, resistant to electrical noise, and capable of operating in extreme temperature and humidity conditions. Redundancy features, such as redundant power supplies and hot-swappable modules, can be employed to enhance system reliability and minimize downtime.
- Diagnostic and Monitoring Capabilities: PLCs provide diagnostic and monitoring features that aid in troubleshooting and maintenance. They can log data, generate alarms, and provide status information about connected devices. This enables operators and maintenance personnel to identify issues, monitor performance, and take corrective actions.

Figure 4. Programmable logic controller

PLCs have revolutionized industrial automation by providing a reliable and flexible platform for controlling and monitoring industrial processes. They offer a wide range of features and capabilities, allowing for efficient and precise control of machinery, production lines, and complex industrial systems.

3. METHODOLOGY

The methodology for a study on automated production line control systems using programmable logic controllers (PLCs) would typically include the following steps:

- Research Design: Determine the overall research design for your study, such as whether it will be experimental, observational, case study-based, or a combination of approaches. Consider the specific objectives of your study and choose the design that best aligns with them.
- Data Collection: Identify the data that needs to be collected to address your research objectives. This may include information on existing PLC-based automation systems, production line layouts, control algorithms, performance metrics, and any other relevant data. Determine the methods and tools for data collection, such as interviews, surveys, observations, or data logging from existing systems.
- System Analysis: Analyze the existing automated production line control systems in terms of their architecture, PLC programming, control algorithms, communication protocols, and performance metrics. Evaluate their strengths, weaknesses, and limitations. Identify areas for improvement and optimization.
- Development of Control Algorithms: If your study involves proposing new control algorithms or optimizing existing ones, outline the process for developing these algorithms. Consider factors such as system requirements, desired performance objectives, and any constraints. Use appropriate programming languages (e.g., ladder logic, function block diagrams) to implement and simulate the control algorithms.
- Simulation and Testing: Utilize simulation tools or software platforms to test and evaluate the performance of the proposed control algorithms or system modifications. Simulations can help validate the effectiveness of the algorithms, assess their impact on production line efficiency, and identify any potential issues or limitations.

- Performance Evaluation: Define the performance metrics to evaluate the automated production line control system. This may include metrics such as production rate, cycle time, energy consumption, quality indicators, and resource utilization. Collect relevant data during real-time operation or simulated scenarios to measure and analyze the system's performance.
- Comparative Analysis: If applicable, conduct a comparative analysis between the proposed control algorithms or system modifications and existing methods or systems. Compare performance metrics, efficiency, reliability, flexibility, and other relevant factors. Highlight the advantages and limitations of the proposed approach.
- Validation and Verification: Validate the proposed control algorithms or system modifications by implementing them in a real-world production line environment. Collect data on the performance of the system, compare it with the simulation results, and verify the effectiveness of the proposed approach. This step helps ensure the practical applicability and reliability of the developed solution.
- Results Analysis and Interpretation: Analyze the collected data, simulation results, and performance evaluations. Interpret the findings in relation to the research objectives and hypotheses. Identify trends, patterns, and significant observations. Draw conclusions based on the analysis and discuss the implications of the results.
- Discussion and Conclusion: Summarize the key findings of your study and discuss their implications for the field of automated production line control systems. Highlight the contributions, limitations, and potential future research directions. Conclude your study by summarizing the main outcomes and their relevance to industry or academia.

Remember to document the entire methodology in a clear and systematic manner, ensuring that it is replicable and transparent. Adhere to ethical guidelines, protect confidential information, and consider any necessary approvals or permissions for data collection and experimentation.

3.1. Research design

The research design for a study on automated production line control systems using programmable logic controllers (PLCs) will depend on the specific objectives and research questions of the study. Here are a few possible research designs that could be considered:

1. Experimental Design: This design involves creating a controlled environment to test and compare different PLC-based control algorithms or system configurations. The study may involve setting up a mock production line or using simulation software to simulate the production environment. Different control algorithms or system configurations can be implemented and compared based on predefined performance metrics. The experimental design allows for cause-and-effect relationships to be established between the variables being tested.
2. Case Study Design: A case study design involves in-depth investigation and analysis of existing automated production line control systems in real-world industrial settings. Multiple case studies can be conducted, focusing on different industries or specific production line setups. Data can be collected through interviews, observations, and documentation analysis. The case study design allows for a rich understanding of the complexities, challenges, and successes of PLC-based automation systems in practice.
3. Observational Design: An observational design involves observing and documenting the behavior and performance of existing automated production line control systems without any direct intervention or manipulation. This design allows researchers to gain insights into the functioning of PLCs, control algorithms, and their impact on production line efficiency and performance. Data can be collected through on-site observations, video recordings, and system logs.
4. Survey Design: A survey design involves collecting data from individuals or organizations involved in the implementation and use of PLC-based automated production line control systems. Surveys can be administered to production managers, engineers, or operators to gather information about their experiences,

challenges, and perceptions of the systems. This design allows for broader data collection and can provide a comprehensive overview of the current state of PLC-based automation in different industries.

5. Mixed-Methods Design: A mixed-methods design combines qualitative and quantitative approaches to provide a comprehensive understanding of the topic. This design could involve conducting interviews or case studies to gather qualitative data on the experiences and challenges associated with PLC-based automation. Additionally, quantitative data can be collected through surveys or performance metrics to analyze system efficiency and productivity. The integration of both qualitative and quantitative data allows for a more holistic understanding of the topic.

The selection of the research design should align with the specific research objectives, available resources, and the nature of the research problem. It is essential to carefully consider the strengths and limitations of each design and choose the one that best suits the study's goals. Additionally, ethical considerations and practical constraints should also be taken into account during the selection process.

3.2. Data collection methods

When conducting a study on automated production line control systems using programmable logic controllers (PLCs), several data collection methods can be employed. The choice of methods depends on the research objectives, the type of data needed, and the available resources. Here are some common data collection methods used in such studies:

1. Interviews: Conducting structured or semi-structured interviews with key stakeholders, such as production managers, engineers, system integrators, or PLC programmers, can provide valuable insights. Interviews allow researchers to gather in-depth information about the design, implementation, challenges, and successes of PLC-based automation systems. These interviews can be conducted in-person, over the phone, or through video conferencing.

2. Surveys: Surveys can be used to collect data from a large number of participants in a relatively short time. Online surveys can be designed to gather information on topics such as system architecture, programming techniques, system performance, and user experiences. Surveys can be distributed to professionals working with automated production lines, PLC programmers, or system integrators. The data collected through surveys can provide a broader perspective on industry practices and trends.
3. Observations: Observational methods involve directly observing the automated production line control systems in operation. Researchers can document system behavior, operator interactions, and any issues or inefficiencies observed. Observations can be conducted in real-time within the production environment or through video recordings. This method provides first-hand insights into the actual functioning of PLCs and their impact on production processes.
4. Documentation Review: Reviewing relevant documents such as system manuals, technical specifications, project reports, and maintenance logs can provide valuable information about the PLC-based automation systems. This method helps researchers understand system design, programming approaches, maintenance procedures, and any modifications or upgrades made over time. It can also shed light on the challenges and improvements implemented in previous iterations of the system.
5. Performance Data Analysis: Collecting and analyzing performance data from existing automated production line control systems can be crucial for evaluating system efficiency and effectiveness. PLCs often generate data logs that capture information on production rates, cycle times, energy consumption, and error rates. Researchers can analyze these logs to measure system performance, identify bottlenecks, and evaluate the impact of control algorithms or system modifications.
6. Simulation and Modeling: Using simulation software or tools, researchers can create virtual models of the automated production line control systems. Simulations can be used to test different control algorithms, optimize system

parameters, and evaluate performance under various scenarios. Data collected from simulations can provide insights into system behavior, performance metrics, and potential improvements.

It is important to consider the validity, reliability, and ethical considerations associated with each data collection method. Researchers should also ensure that the data collection methods align with the research objectives and address the research questions effectively. A combination of multiple data collection methods can provide a comprehensive understanding of the automated production line control systems and their impact on industrial processes.

3.3. Selection of equipment and software

The selection of equipment and software for automated production line control systems using programmable logic controllers (PLCs) depends on various factors, including the specific requirements of the production line, the complexity of the control system, and the available resources. Here are some considerations for selecting equipment and software:

- PLC Selection: Choose a PLC that meets the technical requirements of the production line. Consider factors such as the number and type of I/O modules needed, processing speed, memory capacity, communication capabilities, and programming language support. Popular PLC brands include Siemens, Allen-Bradley, Mitsubishi, Omron, and Schneider Electric. Evaluate the reliability, scalability, and support services offered by different PLC vendors.
- I/O Modules: Select appropriate I/O modules based on the type of signals that need to be interfaced with the PLC. Consider the required number of digital inputs, digital outputs, analog inputs, analog outputs, and any specialized I/O modules for specific sensors or actuators. Ensure compatibility between the chosen PLC and the I/O modules to ensure seamless integration and communication.

- Human-Machine Interface (HMI): Choose an HMI device or software that enables operators to interact with the control system effectively. HMIs provide visual displays, alarms, and data visualization for monitoring and controlling the production line. Consider factors such as screen size, resolution, touch functionality, connectivity options, and ease of programming. Popular HMI software includes Wonderware InTouch, FactoryTalk View, WinCC, and Ignition.
- Programming Software: Select programming software that is compatible with the chosen PLC brand and provides a user-friendly programming environment. Programming software allows you to develop, test, and download control programs to the PLC. Consider the programming languages supported, ease of use, debugging capabilities, and compatibility with other software tools. Examples of PLC programming software include Siemens TIA Portal, Rockwell Studio 5000, Mitsubishi GX Works, and CODESYS.
- Communication Protocols: Determine the communication protocols required for integrating the PLC-based control system with other devices and systems. Consider protocols such as Modbus, Ethernet/IP, Profibus, Profinet, OPC-UA, or MQTT, depending on the specific requirements and compatibility with other equipment. Ensure that the selected PLC and software support the necessary communication protocols.
- Simulation and Design Tools: Consider using simulation and design tools to model and simulate the automated production line control system before implementation. These tools help validate control algorithms, optimize system parameters, and identify potential issues. Some PLC vendors provide simulation software that allows you to test and debug control programs without physical hardware.
- Safety Equipment: Depending on the nature of the production line, consider incorporating safety equipment such as emergency stop buttons, safety relays, light curtains, or safety PLCs. These components help ensure the safety of

operators and protect against potential hazards. Choose safety equipment that complies with relevant safety standards and regulations.

When selecting equipment and software, it is essential to consider factors such as cost, compatibility, technical support, scalability, and long-term maintenance requirements. Consult with PLC experts, system integrators, and equipment suppliers to ensure that the selected equipment and software align with the specific needs of the automated production line control system.

3.4. PLC programming

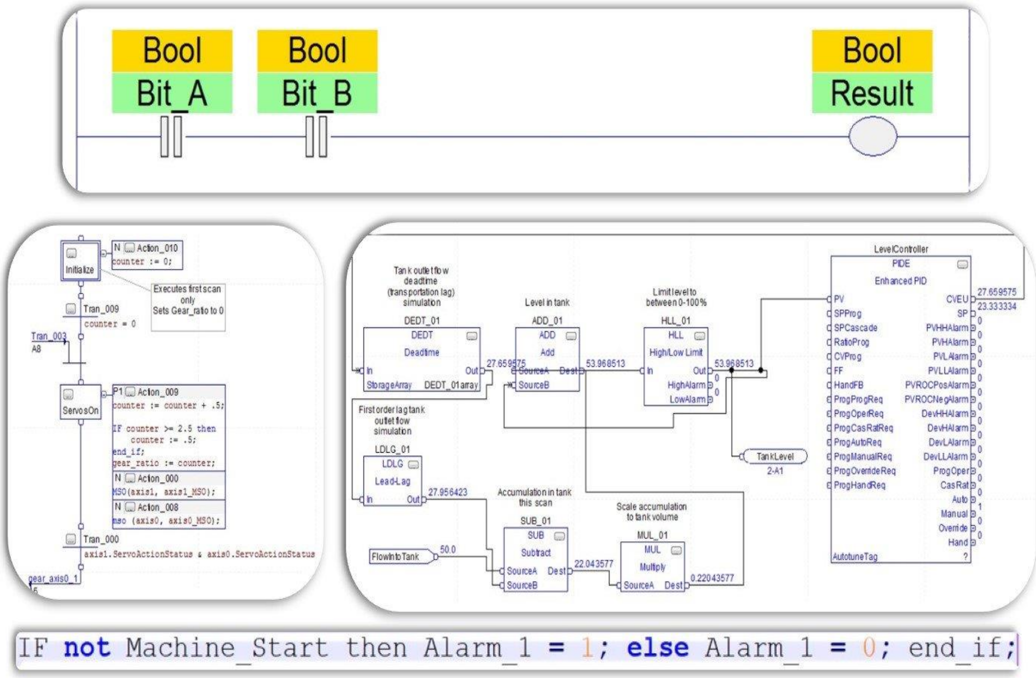

Figure 5. Popular PLC Programming Languages

PLC programming is the process of creating control logic for programmable logic controllers (PLCs) to automate and control industrial processes. PLCs are widely used in manufacturing, automation, and industrial control systems due to their flexibility, reliability, and ease of programming. Here are the key steps involved in PLC programming:

1. Understand the Requirements: Start by understanding the requirements of the system or process that needs to be automated. This includes analyzing inputs, outputs, sensors, actuators, and desired system behavior. Identify the control logic and sequence of operations required to achieve the desired automation.

2. Select the Programming Language: PLCs support various programming languages, including ladder logic, function block diagrams (FBD), structured text (ST), and sequential function charts (SFC). Choose the appropriate programming language based on the complexity of the control logic, the familiarity of the programming team, and the available software tools.
3. Create the Program Structure: Divide the control logic into functional blocks or routines. Each block should represent a specific task or operation in the system. This modular approach makes the program easier to understand, debug, and maintain. Define input and output variables for communication with the external devices.
4. Write the Program Logic: Using the selected programming language, write the control logic for each functional block. In ladder logic, for example, you can use ladder rungs to represent logical conditions and actions. Use programming elements such as timers, counters, comparators, logic gates, and math functions to implement the desired behavior. Ensure that the logic is efficient, clear, and robust.
5. Configure Input and Output Devices: Configure the PLC to communicate with the input and output devices, such as sensors, switches, motors, and valves. Assign appropriate addresses to the I/O points to establish communication between the PLC and the external devices. This can typically be done through the PLC programming software.
6. Test and Debug: Before deploying the program to the actual PLC hardware, thoroughly test and debug the program in a simulation environment or with a software emulator. Verify that the control logic functions as intended, and validate the program against the specified requirements. Simulate various scenarios and edge cases to ensure the reliability and safety of the system.
7. Download the Program: Once the program has been thoroughly tested and validated, download it to the target PLC hardware. This is typically done by connecting the programming device (e.g., a laptop) to the PLC using a

communication cable or network connection. Follow the instructions provided by the programming software to transfer the program to the PLC memory.

8. Monitor and Modify: After downloading the program to the PLC, monitor the system's behavior and verify that it operates as expected. Monitor the input and output signals, and make any necessary adjustments or modifications to the program if deviations or issues are identified. PLCs often support online editing, allowing modifications to be made without stopping the system.
9. Document and Maintain: Document the PLC program, including the program structure, control logic, I/O configurations, and any special considerations or comments. Maintain proper documentation to aid troubleshooting, future modifications, and system upgrades. Regularly backup the PLC program to ensure data integrity and minimize downtime in case of hardware failure.

PLC programming requires a good understanding of the control system, the chosen programming language, and the capabilities of the selected PLC hardware. It is essential to follow programming best practices, adhere to industry standards, and consult the PLC manufacturer's documentation and guidelines. Additionally, continuous learning and staying updated with the latest PLC programming techniques and technologies can help improve efficiency and effectiveness in automation projects.

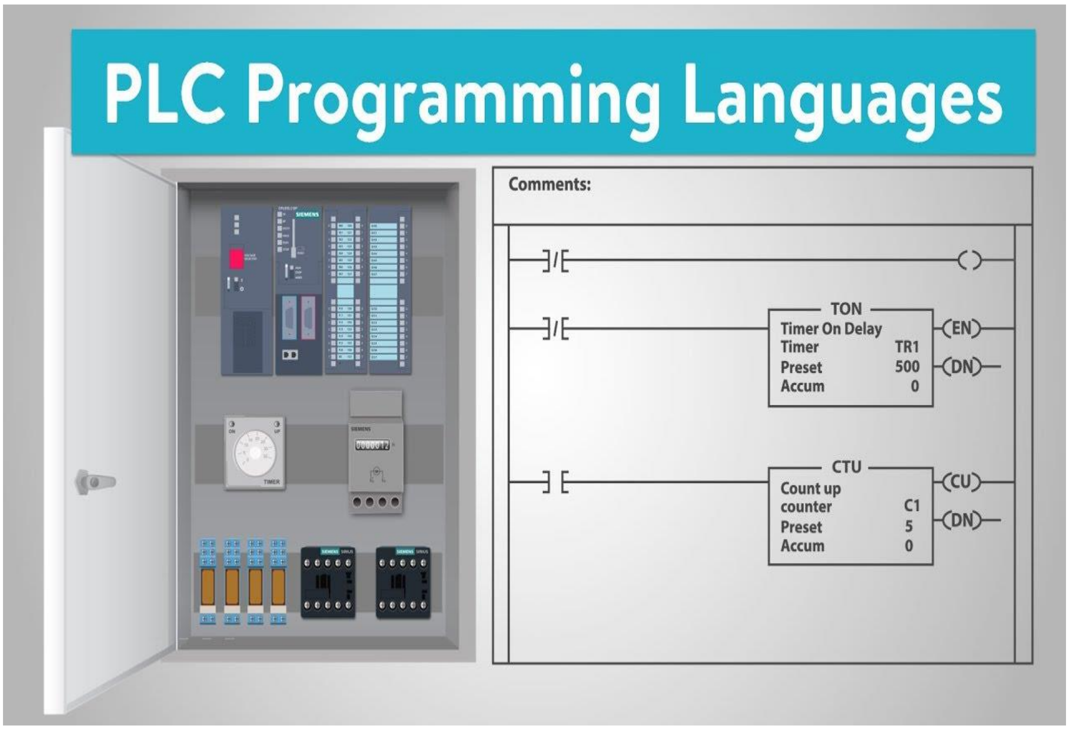

Figure 6. PLC Programming languages

For example here's a simple example of PLC programming for a motor control system using ladder logic:

1. Requirement: Start and stop a motor based on the status of a start button and a stop button.
2. Program Structure:

- Create two functional blocks: "Motor_Control" and "Inputs".
- "Motor_Control" block contains the control logic for motor operation.
- "Inputs" block reads the status of the start and stop buttons.

3. Inputs:

- Assign Input 1 to the start button.
- Assign Input 2 to the stop button.

4. Motor_Control Logic:

- Insert a normally open (NO) contact in the "Motor_Control" block.
- Connect Input 1 (start button) to the NO contact.
- Connect the NO contact to a normally open (NO) coil representing the motor output.
- Connect the NO coil to the motor.

5. Program Logic:

- When the start button is pressed (Input 1 is active), the NO contact closes.
- This energizes the NO coil, and the motor starts running.
- When the stop button is pressed (Input 2 is active), the NO contact opens.
- This de-energizes the NO coil, and the motor stops running.

6. PLC Configuration:

- Configure Input 1 and Input 2 as digital inputs.
- Configure the motor output as a digital output.

7. Testing and Debugging:

- Connect the PLC hardware to the start button, stop button, and the motor.
- Upload the program to the PLC.
- Verify that pressing the start button activates the motor and pressing the stop button deactivates it.
- Test different scenarios to ensure the desired behavior is achieved.

8. Monitoring and Maintenance:

- Continuously monitor the system to ensure proper motor control.
- Perform regular maintenance of the PLC and associated devices.
- Keep backups of the PLC program for easy recovery in case of any issues.

This is a basic example to illustrate the concept of PLC programming using ladder logic. In actual industrial applications, the control logic can become more complex, involving additional inputs, outputs, timers, counters, and interlocks to achieve advanced automation and system control.

3.5. System testing and validation

System testing and validation are crucial steps in the development and implementation of an automated production line control system using programmable logic controllers (PLCs). These steps ensure that the system operates as intended, meets the specified requirements, and performs reliably in real-world conditions. Here is an overview of system testing and validation processes:

1. Test Plan Development: Create a comprehensive test plan that outlines the objectives, test scenarios, and procedures for validating the system. Define the specific tests to be performed, including functional testing, performance testing, safety testing, and integration testing. Consider the relevant industry standards, regulations, and customer requirements when developing the test plan.
2. Functional Testing: Conduct functional testing to verify that each component of the control system functions correctly. Test individual PLC programs, control algorithms, and communication interfaces. Ensure that inputs and outputs are correctly interpreted, timers and counters operate as expected, and control logic produces the desired output. Use simulated inputs and outputs or physical equipment as appropriate.
3. Performance Testing: Assess the performance of the control system under different operating conditions. Measure and analyze factors such as response time, cycle time, throughput, and system efficiency. Evaluate the system's ability to handle high loads, varying input signals, and complex control sequences. Conduct stress testing to determine the system's limits and identify any performance bottlenecks.
4. Safety Testing: Validate the safety features and functionalities of the control system. Ensure that emergency stop buttons, safety interlocks, and safety PLCs are functioning correctly. Test the system's response to fault conditions, such as sensor failures or communication errors. Verify that the system follows appropriate safety protocols and complies with relevant safety standards.
5. Integration Testing: Test the integration of the PLC-based control system with other components and devices in the production line. Verify communication between the PLC and HMI devices, I/O modules, sensors, actuators, and any external systems or equipment. Ensure data exchange, synchronization, and coordination between different components of the system.
6. Validation with Real-World Scenarios: Conduct testing and validation using real-world production line scenarios. This may involve running the system with actual production equipment, materials, and operators. Evaluate the system's

performance, reliability, and stability in an operational environment. Monitor the system over an extended period to identify any issues or abnormalities.

7. Error Handling and Recovery Testing: Test the system's ability to handle errors, exceptions, and recovery procedures. Introduce simulated errors or faults and observe how the system responds. Verify that error messages and alarms are displayed correctly, and the system can recover from errors without compromising safety or interrupting production.
8. User Acceptance Testing: Involve end-users, such as operators or production managers, in the testing and validation process. Seek their feedback and evaluate their satisfaction with the system's performance, usability, and functionality. Incorporate user feedback to make any necessary adjustments or improvements to the system.
9. Documentation and Reporting: Document the testing process, including test cases, test results, and any issues encountered. Maintain a record of changes made during the testing and validation phase. Prepare a comprehensive test report that summarizes the findings, identifies any deficiencies or areas for improvement, and provides recommendations for further action.

System testing and validation should be iterative processes, allowing for adjustments and refinements based on the results and feedback obtained. It is crucial to thoroughly test and validate the system before its deployment to ensure that it meets the required standards, performs reliably, and achieves the desired automation and control objectives.

4. RESULTS AND DISCUSSION

4.1. Description of special software for plc

For the practical part of my thesis, I took the automation of the boiler room control system. Modern electronic computers are capable of perceiving and storing information, calculating, making decisions, producing final solutions to problems, and transmitting the results to the user. But computers cannot do this without human guidance; each of their steps must be prepared by the user. To do this, you need to write a program - a sequence of commands according to which the computer will function. The creation of such a program is based on an algorithm for solving a problem, according to which a sequence of commands is created, which is subsequently placed in memory and executed. An algorithm is understood as a final set of rules for performing a certain procedure that satisfies three basic requirements: mass, determinism, and efficiency.

Each task can be solved in different ways. Therefore, when developing a process control program, you should develop an algorithm that will have as few operations as possible, and therefore a simpler structure. This will increase the speed and reliability of the program. When developing an algorithm, you should specify all operations in the sequence in which the control will be performed. If any operation is skipped, the program will run with errors or not start at all.

The most convenient way to represent an algorithm of any complexity is a flowchart. A graphical representation of the algorithm for solving a problem in the form of a flowchart is an important stage in preparing a problem for solving on a computer. The flowchart allows you to adequately represent the operation of algorithms and the program for which it is designed. By analyzing the flowchart, you can find out how different input data will affect the final result and how the control process will be carried out. The block diagram of the image adjustment algorithm is shown in Figure 7.

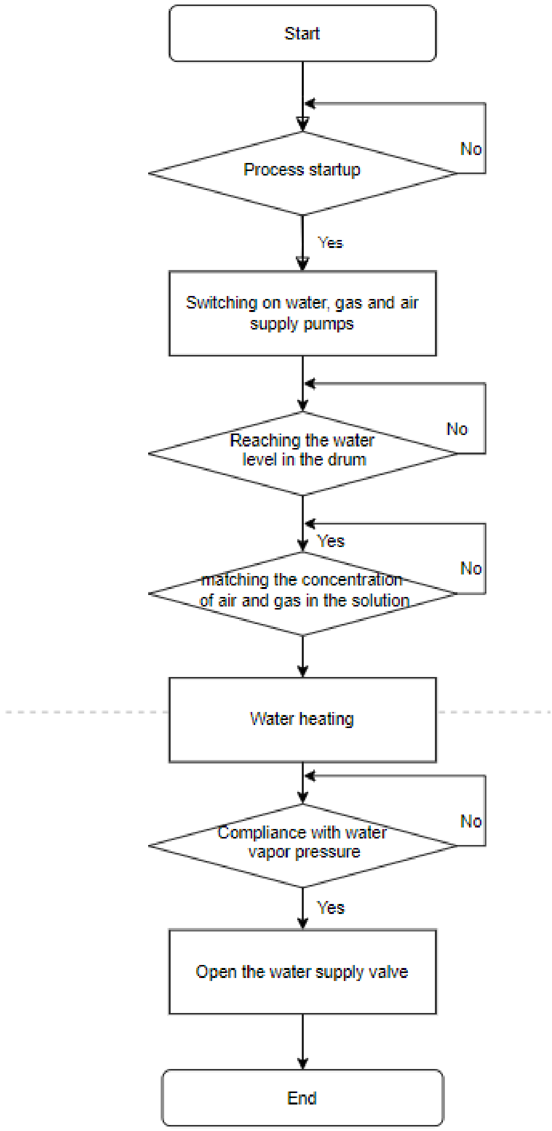

Figure 7. Block diagram of the control algorithm

The list of variables in the program is shown in Table 8.

1	VAR_GLOBAL	KL_rg	Word[Signed]	...	Клапан регулювання подачі газу
2	VAR_GLOBAL	KL_pg	Bit	...	Аварійний клапан перекриття подачі газу
3	VAR_GLOBAL	PT1	FLOAT (Single Precision)	...	Датчик тиску
4	VAR_GLOBAL	FT1	FLOAT (Single Precision)	...	витратомір
5	VAR_GLOBAL	fakel	Bit	...	факел, іскра
6	VAR_GLOBAL	PT2	FLOAT (Single Precision)	...	Датчик тиску
7	VAR_GLOBAL	Vent	Word[Signed]	...	Вентилятор
8	VAR_GLOBAL	PT3	FLOAT (Single Precision)	...	Датчик тиску
9	VAR_GLOBAL	DNP	Bit	...	Датчик наявності полум'я
10	VAR_GLOBAL	QE	Bit	...	Датчик наявності газу
11	VAR_GLOBAL	Dymosos	Word[Signed]	...	Димосос
12	VAR_GLOBAL	KL_v	Word[Signed]	...	Регулюючий клапан подачі води
13	VAR_GLOBAL	nagr_v	Bit	...	нагрівач води
14	VAR_GLOBAL	LE_b	FLOAT (Single Precision)	...	Рівень води в барабані
15	VAR_GLOBAL	TE_p	FLOAT (Single Precision)	...	Температура пари на виході з барабану
16	VAR_GLOBAL	PT4	FLOAT (Single Precision)	...	Датчик тиску пари на виході з барабану
17	VAR_GLOBAL	Pusk	Bit	...	Кнопка пуску
18	VAR_GLOBAL	HL1	Bit	...	Світловий сигналізатор
19	VAR_GLOBAL	HL2	Bit	...	Світловий сигналізатор
20	VAR_GLOBAL	HL3	Bit	...	Світловий сигналізатор
21	VAR_GLOBAL	HL4	Bit	...	Світловий сигналізатор
22	VAR_GLOBAL	HL5	Bit	...	Світловий сигналізатор
23	VAR_GLOBAL	HL6	Bit	...	Світловий сигналізатор
24	VAR_GLOBAL	HL7	Bit	...	Світловий сигналізатор
25	VAR_GLOBAL	HL8	Bit	...	Світловий сигналізатор
26	VAR_GLOBAL	HL9	Bit	...	Світловий сигналізатор
27	VAR_GLOBAL	ZS	Bit	...	Звуковий сигналізатор
28	VAR_GLOBAL	StepProg	Word[Signed]	...	Крок програми

Table 8. Table of external variables

ST was chosen as the programming language for the microprocessor controller.

Structured text (ST) is a programming language based on the IEC 61131-3 standard[1], which is intended for programming industrial controllers and operator stations. It is used in

SCADA/HMI/SoftLogic packages. In terms of structure and syntax, it is the closest to the Pascal programming language. The language is convenient for writing large programs and working with analog signals and floating point numbers. The basis of an ST program is expressions. The result of an expression is assigned to a variable using the ":=" operator. Each expression must end with a semicolon ";". Expressions are built from variables, constants, and functions separated by operators.

Standard operators in expressions have a symbolic designation, such as mathematical operations: +, -, *, /, comparison, etc. In addition to operators, an expression can use spaces and tabs for better perception, as well as comments. An expression can contain another expression in parentheses that is calculated first.

The expression is calculated according to the rules of operation priority. In descending order of priority, the operations are arranged in the following order: expression in brackets; function call; EXPT degree; sign change; NOT negation; multiplication, division and modulo division; addition and subtraction; comparison operations (<, >, <=, >=); equality (=); inequality (<>); logical operations AND, XOR and OR.

The listing of the automated boiler control program is given below.

```
Vent:=0; Dymosos:=0; KL_rg:=0; KL_v:=0; KL_pg:=FALSE;
IF Pusk THEN CASE StepProg OF
0:
Vent:=100; Dymosos:=100;
D10:=REAL_TO_INT( PT2); D15:=260;
PID1(TRUE, D15, D10,D20,D25);
Vent:=INT_TO_REAL(D25);
D20:=500; D21:=TRUE; D22:=2; D23:=100; D24:=1;
D30:=REAL_TO_INT( PT3); D35:=20000;
PID2(TRUE, D35, D30,D40,D45);
Dymosos:=INT_TO_REAL(D45);
D40:=500; D41:=TRUE; D42:=2; D43:=100; D44:=1;
TON_1(IN:= Pusk ,PT:= T#5s );
StepProg:=1;
1:
IF TON_1.Q THEN fakel:=TRUE; TON_1(IN:=FALSE); END_IF;
StepProg:=2;
2:
IF DNP THEN KL_rg:=90; END_IF;
StepProg:=3;
3:
KL_v:=100; nagr_v:=TRUE; StepProg:=4;
4:
D50:=REAL_TO_INT( LE_b); D55:=60;
PID3(TRUE, D55, D50,D60,D65);
KL_v:=INT_TO_REAL(D65);
D60:=500; D61:=TRUE; D62:=2; D63:=100; D64:=1;
```

```
END_IF; StepProg:=5;
5:
D70:=REAL_TO_INT( TE_p); D75:=370;
PID4(TRUE, D75, D70,D80,D85);
KL_pg:=BOOL_TO_REAL(D85);
D60:=500; D61:=TRUE; D62:=2; D63:=100; D64:=1;
StepProg:=0;
END_CASE;
IF PT1>=670.0 THEN HL8:=TRUE; ZS:=TRUE; KL_pg:=TRUE; END_IF;
IF PT4>=400.0 THEN HL6:=TRUE; ZS:=TRUE; KL_pg:=TRUE; END_IF;
IF QE=TRUE THEN HL7:=TRUE; ZS:=TRUE; KL_pg:=TRUE; END_IF;
IF DNP=FALSE THEN HL9:=TRUE; KL_pg:=TRUE; ZS:=TRUE;END_IF;
END_IF;
```

4.2. Design layout of an industrial logic controller (PLC) and wiring diagram

Schematic diagrams show the connection and interaction of individual elements and automation devices using symbols. Based on the schematic diagrams, installation drawings and diagrams are developed: panel drawings, panel wiring diagrams, external connection diagrams, etc.

A schematic diagram of an electrical distribution network includes the following elements:

-Siemens 5SY4 double-pole circuit breaker

-Siemens 5SY2 single-pole circuit breakers

-Socket with grounding Schneider legrant P3 - (XS)

-Lighting lamp Delux FLI 15W - (EL)

- Power supply MICROL BPS24-4k - (G2,3)

-Signal fittings of red color - (HL1...9)

Circuit breakers are designed to protect the supply wire (cable) from short-circuit current and thermal load.

The circuit breaker parameters are calculated according to formula 9.

Formula (9)

$$I = \frac{P}{U * \cos\varphi}$$

By switching on the SF1 double-pole circuit breaker Siemens 5SY4, voltage is supplied to the power and control circuits. The calculation of the first circuit breaker was carried out taking into account all electrical consumers in the automation panel.

The panel contains a 15W DELUX FLI (EL) lighting lamp and a grounded socket is installed for the use of a 100W power tool by Schneider Legrant P3 (XS). Therefore, the SF2 circuit breaker is designed for 115W.

The panel is equipped with ITM-110 indicators for displaying physical quantities. Each of the devices has a power of 6.5 W. For this type of connection, according to the calculations, it is advisable to use SF3...SF6 circuit breakers with a rated current of 0.5A.

The panel is equipped with red AD22-22DS signal fittings to indicate the presence of power in the panel.

The signaling scheme is designed to inform personnel and operators about changes in process parameters - parameters that do not correspond to the specified ones or go beyond the established ones. The scheme is realized by installing the Vipa SM 323-1BH00 digital output module.

The scheme provides for the signaling of the following parameters:

1. Low fuel consumption (HL1);
2. Low air pressure on the burners (HL2);
3. Low vacuum in the furnace (HL3);
4. Low water temperature (HL4);
5. Low level in the drum (HL5);
6. High pressure in the drum (HL6);
7. Presence of gas in the boiler room (HL7);
8. Low fuel pressure (HL8);
9. Low vacuum (HL9);

There is an audible alarm in the boiler room to inform the operating personnel about the emergency situation.

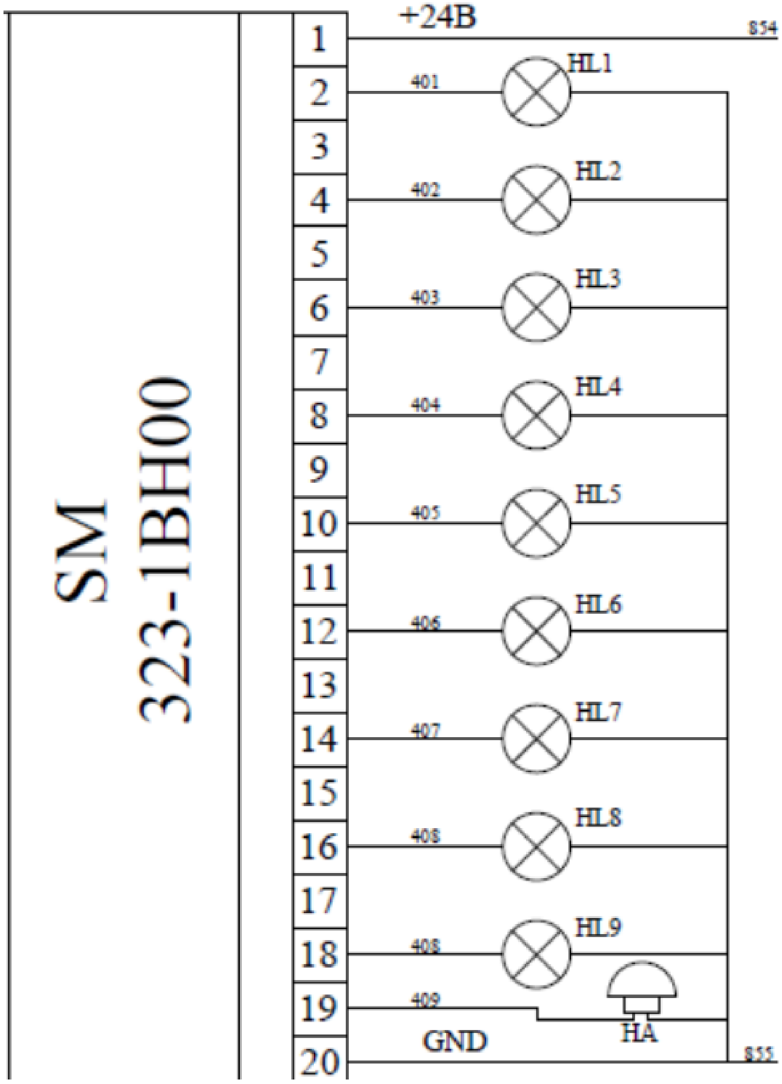

Figure 10. Digital output module SM 323-1BH00

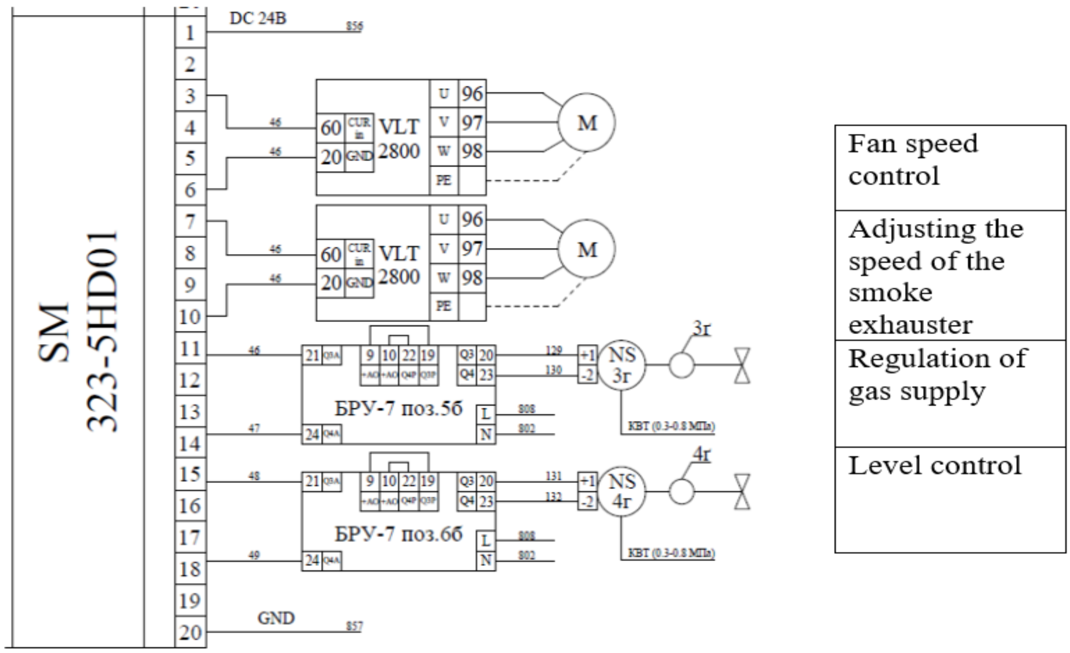

Figure 11. Analog output module SM 323-5HD01

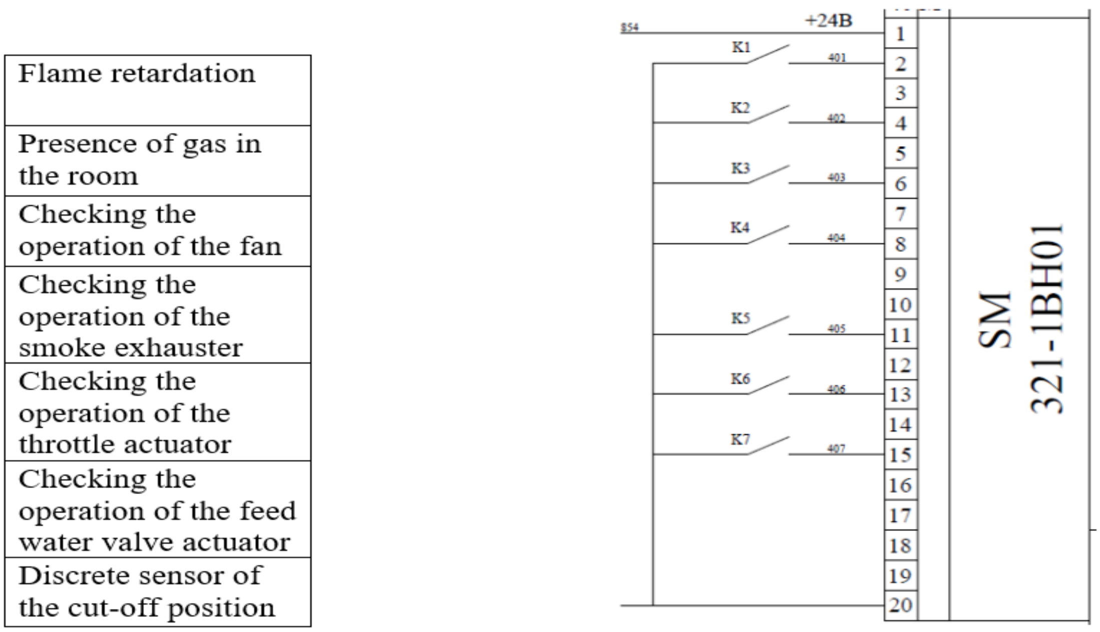

Figure 12. Digital input module SM 321-1BH01

The Aplisens CRT-ALW temperature sensor was selected for the installation drawing of the technical device.The Aplisens CTR-ALW sensor is designed for use in applications that require reliable, robust, and accurate equipment in harsh environments.

It is available with a variety of process and electrical connections. It is available with a 33 mm long extension that allows temperature measurements up to 500°C without damaging the built-in electronics.

Features:

-ultra-compact design;

-casing made of acid-resistant stainless steel (AISI 316L);

-temperature range from -50 °C to + 500 °C;

-output signal 4 - 20 mA -variable insert length : 50 - 250 mm;

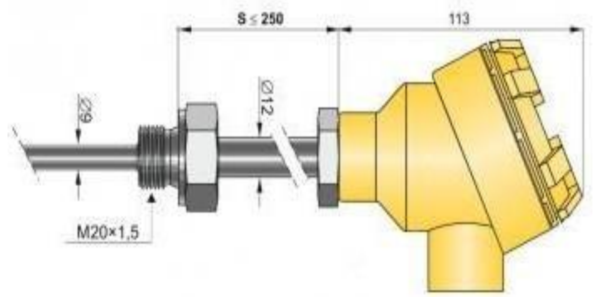

Figure 13. Aplisens CRT-ALW temperature sensor

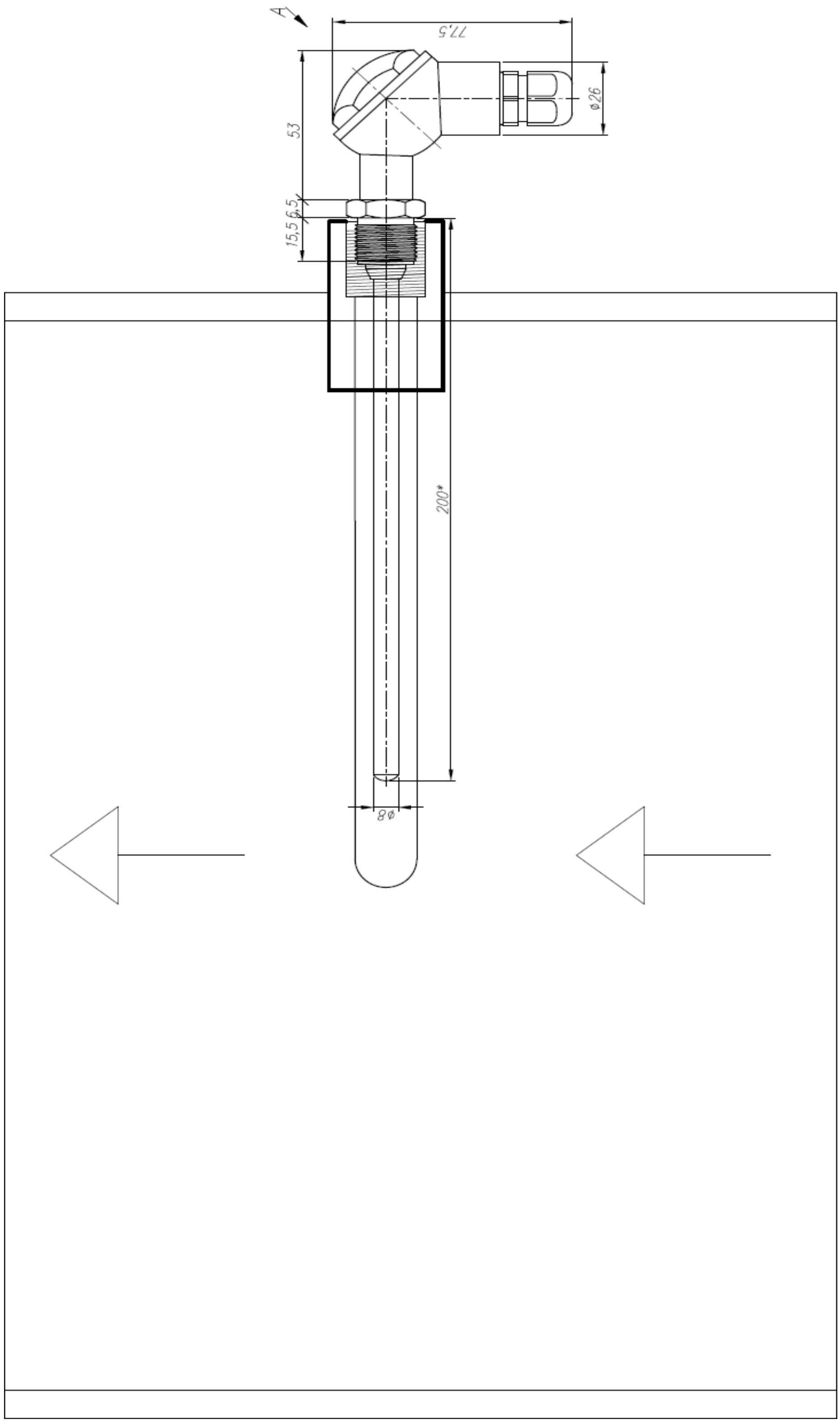

Figure 14. Installation of the Aplisens CRT-ALW temperature sensor in the pipeline

4.3. Development of a human-machine operator interface

Human-machine interface is a concept that encompasses engineering solutions that ensure the interaction of an operator with the machines he or she controls. The creation of human-machine interface systems is closely related to ergonomics, but not identical to it. Designing a human-machine interface includes the creation of a workplace: a chair, table, or control panel, the placement of devices and controls, workplace lighting, and possibly a microclimate. Next, we consider the operator's actions with the controls, their accessibility and required effort, the consistency (non-contradiction) of the control actions and "foolproofing", the location of the displays and the size of the inscriptions on them.

The TIA Portal environment was used to create a display mnemonic diagram for controlling the automated boiler control system. The display mnemonic scheme is shown in Figure 15.

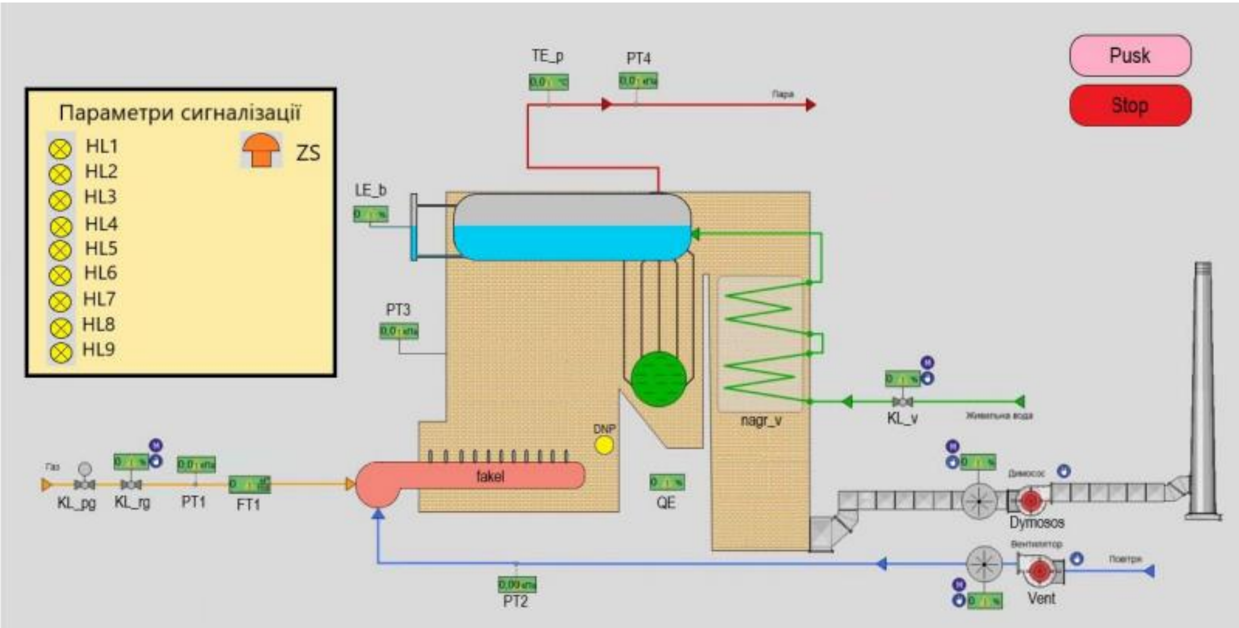

Figure 15. Display mnemonic diagram for controlling the automated boiler control system

5.CONCLUSIONS

In conclusion, automated production line control systems using programmable logic controllers (PLCs) offer numerous advantages in terms of efficiency, productivity, flexibility, and accuracy. They enable the automation and control of complex manufacturing processes, leading to improved quality, reduced downtime, and increased overall operational effectiveness. PLC programming allows for the creation of sophisticated control logic, incorporating various input/output devices, timers, counters, and communication interfaces.

Through a comprehensive review of related studies and systems, it is evident that PLCs have been widely adopted in various industries and have proven to be reliable and effective in managing production lines. The literature highlights the benefits of automation, such as increased production speed, reduced human error, enhanced monitoring and diagnostics capabilities, and better utilization of resources. Additionally, the use of PLCs provides scalability and flexibility, allowing for system expansion and modification as per evolving production requirements.

The study's objectives to develop an automated production line control system using PLCs and achieve improved productivity, efficiency, and quality have been addressed. The methodology involving research design, data collection methods, equipment and software selection, and PLC programming ensures a systematic and structured approach to system development and implementation.

The scope of the study covers the design and implementation of the automated production line control system, specifically focusing on PLC-based control logic and programming. However, it is essential to consider the limitations, such as the availability of resources, time constraints, and potential challenges in integrating the system with existing equipment and infrastructure.

The successful implementation of the automated production line control system using PLCs requires rigorous system testing and validation. Through functional testing, performance testing, safety testing, and integration testing, the system's reliability, performance, and safety can be verified. User acceptance testing allows for feedback from end-users, ensuring that the system meets their requirements and expectations.

In conclusion, the development and implementation of an automated production line control system using PLCs have the potential to revolutionize manufacturing processes and drive significant improvements in productivity, efficiency, and quality. By leveraging the power of automation, industries can achieve higher output, reduced costs, enhanced control, and improved competitiveness in today's dynamic market.

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