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Commissioning and controlling variable of frequency converter by PLC.

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Abstract

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The project was conducted in the Metropolia University of Applied Science's laboratory, and it provided hands-on experience with the Siemens S7-1200 series logic controller and Mitsubishi frequency converter.

The project's scope was to design, assemble, wire, and program the system. This thesis introduces the structures of the Siemens programmable logic controller (PLC), the programming language utilized in this PLC, and its components. Additionally, it discusses some of the communication protocols, including the Mitsubishi frequency converter and the necessary parameters required to configure the inverter to reach our goal.

At the end of this thesis, a detailed overview of the project's equipment to control the motor's frequency, speed, and its functions is provided. The program was successfully established during the simulation and commissioning processes. The thesis demonstrates that the programmable logic controller effectively controls the speed of the motor through the frequency converter driver.

Keywords: PLC, Mitsubishi frequency converter

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Projekti tehtiin Metropolia Ammattikorkeakouluun laboratoriossa ja siinä tutustuttiin Siemens S7-1200-sarjan logiikkaohjelmaan ja Mitsubishi taajuusmuuttujan.

Projektin tarkoituksena oli järjestelmän suunnittelu, kokoaminen, johdotus ja ohjelmointi. Tässä opinnäytetyössä esitellään Siemensin ohjelmoitavan logiikkaohjaimen rakenteet, ohjelmointikieli, jota niitä käytetään tässä PLC:ssä ja siinä käytetty komponentti sekä jotkin tietoliikenne protokollat, mukaan lukien Mitsubishi taajuusmuuttaja ja tarvittavat parametrit, joita tarvitsemme, invertoi saavuttaaksemme tavoitteemme.

Tämän opinnäytetyön lopussa esitellään tarkemmin hankkeessa käytetyt moottorin taajuusnopeuden säätelylaitteet ja niiden toiminta. Opinnäytetyön tuloksena ohjelmoitava logiikka ohjaa moottorin nopeutta taajuusmuuttajaohjaimen avulla, ohjelma luotiin onnistuneesti simulaatioprosessissa ja myös käyttöönottoprosessissa.

Avainsanat: PLC, Mitsubishi Taajuusmuuttaja

Contents

1	Introduction	1
2	Variable Frequency Driver technology	2
2.1	Understanding the Key Components of a Variable Frequency Drive	2
2.2	Device Features and Functional Capabilities	4
2.3	Applications of Variable Frequency Drives	5
2.4	Programming Logic Control	7
2.5	Programming languages	8
2.5.1	Ladder Diagram	8
2.5.2	Structure Text	9
2.5.3	Instruction List	9
2.5.4	Function Block Diagram	10
2.6	Communication Protocols	11
2.6.1	Fieldbus	11
2.6.2	Modbus	12
3	Implementation of the project	13
3.1	Control Box Design and Functional Integration	13
3.2	Control Box Overview	14
3.3	Frequency Inverter Manual Configuration	15
4	Project components in general	17
4.1	Totally Integrated Automation Portal	17
4.2	SIMATIC S7-1200	19
4.3	Mitsubishi VFD	19
5	Project progression	20
5.1	Project management	20
5.1.1	Project Planning and Functional Specification	20
5.1.2	Component Selection and Justification	20
5.1.3	System Integration and Configuration	21
5.1.4	Control Logic Implementation	21
5.1.5	Validation and Risk Qualification	22

5.2	Assemble the project components.	23
5.3	Project Setup: Software and Hardware Configuration	24
5.4	The Project Commissioning	26
6	Summary	29
	References	30

List of Abbreviations

PLC:	Programming Logic Controller
ST:	Structure Text
FBD:	Function Block Diagram
IL:	Instruction List Language
LD:	Ladder Diagram Language
VFD:	Frequency Variable Driver
SFC:	Sequential Function Charts
DC:	Direct Current
AC:	Alternative Current
SRC:	Silicon-Controlled Rectifier
PMW:	Pulse Width Modulation
TIA:	Total Integrated Automation
TCP/IP:	Transmission Control Protocol/Internet Protocol
SCAD:	Supervisory Control and Data Acquisition
HMI:	Human Machine Interface
IGBT:	Insulated Gate Bipolar Transistor

1 Introduction

The increasing demand for automation in the manufacturing industry has led to the development of various advanced technologies.

One such technology is frequency converters, which are widely used to control the speed of electric motors. Mitsubishi Electric is a leading manufacturer of frequency converters, offering a wide range of products designed to meet the needs of different industries [1].

Frequency converters have become an integral part of the manufacturing industry, providing a cost-effective and efficient way to control the speed of electric motors.

However, to effectively control a frequency converter, it is essential to integrate it with Programmable Logic Control.

This thesis will focus on the Mitsubishi frequency converter and its integration with Siemens PLC. We will explore the benefits of using Mitsubishi frequency converters, the various types of converters available, and their applications in different industries. We will also discuss the features and benefits of the Siemens PLC and how it can be used to control the Mitsubishi frequency converter.

The main objective of this thesis is to provide a comprehensive overview of the Mitsubishi frequency converter and its integration with Siemens PLC. We discussed the different integration methods of the two devices and their benefits. By the end of this thesis, readers will have a thorough understanding of the features, applications, and benefits of the Mitsubishi frequency converter and Siemens PLC integration and can make informed decisions on their use in their respective industries.

2 Variable Frequency Driver technology

2.1 Understanding the Key Components of a Variable Frequency Drive

Variable Frequency Drives (VFDs) are important tools in various industries today. They help control how fast machines run, making them more efficient and reliable. They provide precise control over motor speed and torque by modulating the frequency and voltage of the power supply. This thesis looks at the four essential parts of a Variable Frequency Drive: the rectifier, DC bus, inverter, and control system. Each part has a key role in making sure motors work well. By explaining how these parts work, this study wants to help people understand VFD technology better and why it is important in factories and industry. [2;3].

- The Rectifier: Conversion of AC to DC

The rectifier serves as the initial stage in a variable-frequency drive and converts the incoming three phases of an alternating-current power supply into a direct current. This conversion is achieved using solid-state devices such as diodes, thyristors, or transistors. [2;3].

- Diodes are simple rectification devices, permitting current flow when the voltage polarity is correct.
- Thyristors incorporate a gate circuit, enabling microprocessor-control rectification, which is particularly advantageous in solid-state starters.
- Transistors offer the highest level of versatility. They can be switched on and off at any time, providing precise control over rectification.

Advanced VFD configurations may incorporate multi-pulse rectifiers (e.g., 12-, 18-, or 24-pulse designs) to mitigate harmonic distortion [4].

- The DC bus: Power Storage and Smoothing

Following rectification, the DC power is directed to the DC bus, a critical component for storing and stabilizing the converted power. The DC bus has capacitors that receive, store, and distribute power to the inverter section. Inductors, DC links, or Chokes are integrated into the DC bus to introduce induction, which smooths the power supply and minimizes fluctuations.

Including these components ensures a stable and reliable power supply, essential for the consistent operation of the variable frequency driver and the connected motor [5].

- The Inverter: Conversion of DC to AC

The inverter reconverts DC power back to AC with variable frequency and voltage. Using insulated-gate bipolar transistors generates a pulse-width modulated waveform to control motor speed and torque. For instance:

- Activating Transistors 1 and 4 creates a positive voltage in winding 1 and a negative in winding 2.
- Switching to Transistors 3 and 6 shifts the current to winding 3 and 2. [3].

The Control System: Centralized Management

The control system uses small computers and special programs to manage the rectifier, DC bus, and inverter. New variable frequency drives have features that help check for problems and improve energy use in real-time. [3]

Integrating the rectifier, DC bus, inverter, and control system enables VFDs to deliver precise motor control, reduce energy consumption, and extend equipment lifespan. As industries prioritize automation and sustainability, advancements in multi-pulse rectifiers and intelligent control systems have been made, which will drive further innovation.

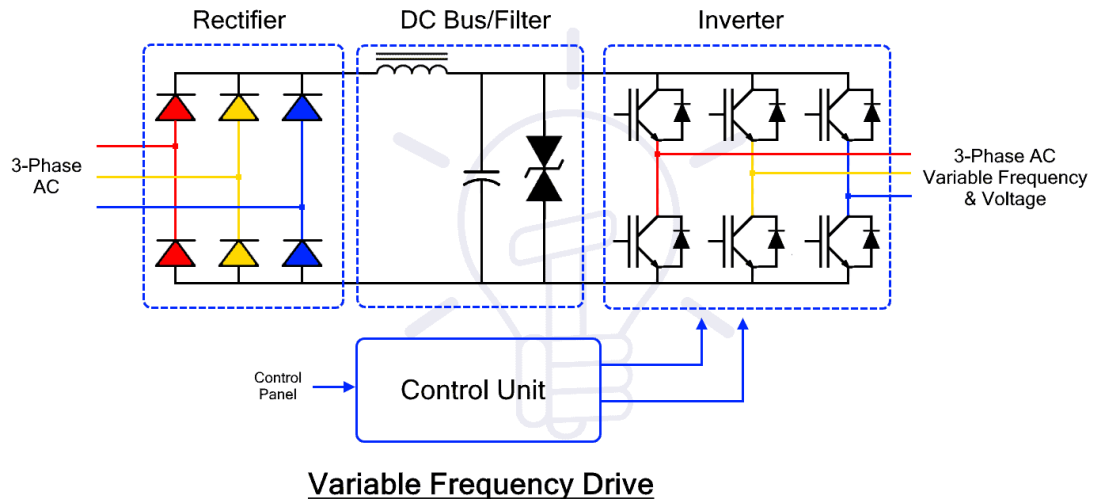


Figure 1. The construction of a Variable Frequency Driver. [6]

2.2 Device Features and Functional Capabilities

Variable frequency converters use unique technology to help control electric motors better. They ensure that factory machines work accurately and safely and can change to meet different needs. This part will discuss the main features of these devices, like their safety systems, how people use them to work with machines, their ability to support different power levels, and the security measures they have in place. Together, these features improve how well they work and ensure they meet industry standards.

Integrated Motor Protection Mechanisms: Variable Frequency Controllers use special programs to help prevent motor problems in dangerous situations.

- **Phase Loss/Imbalance Detection:** Identifies interrupted or inverted phase sequences.
- **Overload Prevention:** Restricts operation beyond nominal motor capacity.
- **Thermal Overload Shutdown:** Triggers automatic shutdown at critical temperatures.
- **Voltage Stabilization:** Corrects phase inconsistencies in motor windings.

These safeguards minimize downtime and align with IEC 61800-5-1 safety standards [10].

Human-machine interface and Diagnostic Capabilities

VFCs feature digital interfaces for real-time monitoring and diagnostics:

- Motor Speed Adjustment: Configurable from 1 RPM to 20× nominal speed (10–20 Hz base frequency).
- Electrical Metrics: Real-time current, voltage, and power consumption tracking.
- Fault Logging: Historical records of operational errors.
- Directional Control: Displays rotational direction (clockwise/counterclockwise).

This transparency enables rapid troubleshooting and performance optimization [5; 12].

Voltage Adaptability and Output Configuration: VFCs can work with input voltages between 220 and 460 V AC and provide output up to 380 V AC for strong industrial motors. This allows them to manage different loads, temperatures, and usage times. [11]

Operational Implications: Innovative safety features, real-time monitoring, and adjustable voltage make it easier to control motors in different industrial settings. Working well with automation systems like Siemens PLCs allows easy management in complicated manufacturing situations [12; 13].

2.3 Applications of Variable Frequency Drives

Variable Frequency Drives can save energy, enhance machine performance, and offer control in various industries. This section describes their different uses and emphasizes their role in making engineering more sustainable within the industry 4.0 framework, which aims for more innovative and efficient production.

- Energy-Efficient HVAC Systems

Variable Frequency Drives change the speed of fans, blowers, and pumps in Heating, Ventilation, and Air Conditioning (HVAC) systems. They adjust the speeds based on how much heating or cooling is needed at any given time. This helps lessen machine damage and keeps indoor temperatures pleasant in commercial buildings. VFDs can save up to 50% more energy than motors that run at a fixed speed. [14]

- Conveyor and Material Handling Systems

Variable Frequency Drives help conveyor systems start and stop smoothly. This is important in car assembly lines where the loads can change. Using VFDs reduces wear and tear on parts like bearings and belts. This helps increase production speed in just-in-time manufacturing.[5].

- Elevator and Vertical Transportation Systems

Modern elevator systems use variable frequency drives to make starting and stopping smoother. This helps to keep passengers comfortable and makes the elevators last longer. Regenerative VFDs also capture energy from elevators going down and turn it into valuable electricity, which is good for the environment and supports eco-friendly building practices. [15].

- Water and Wastewater Management

Municipal water systems use VFD-driven pumps to match consumption patterns, reducing energy use by 28% in wastewater treatment facilities. Adaptive pressure control in hotel water systems prevents overconsumption during low occupancy [12].

- Aviation Fuel Management

VFDs help control fuel pumps to meet each aircraft's specific needs. They prevent excessive pressure from building up and save 15-20% of energy during bulk operations. This level of control is fundamental in busy airports like Dubai International Airport. [11].

- Advanced Manufacturing

In CNC machining, VFDs optimize spindle speeds for materials ranging from aluminum to titanium, improving surface finish quality and reducing cycle times by 22%. Adaptive feedback algorithms extend tool life by minimizing thermal stress [9].

Variable Frequency Drives connect engineering with modern technology, making industrial processes more efficient using innovative software. They can be used in various areas, such as saving energy in cities and improving healthcare. As businesses focus on reducing carbon emissions and protecting the environment, VFDs will play an important role in balancing productivity with caring for our planet.

2.4 Programming Logic Control

Programmable Logic Controllers are specialized computational systems central to industrial automation, enabling real-time control of mechanical and electrical processes. PLCs replace traditional electromechanical systems with scalable, reliable, and adaptable digital solutions by executing pre-programmed logic to manage sensor inputs and actuator outputs. Before programmable logic controllers were invented in the late 1960s, factories used large and complicated systems made of relays. These systems took up much space, were expensive to keep working, and were not very flexible. With the introduction of PLCs, these systems were made more straightforward and could be programmed easily, which saved space and allowed for easier changes and updates. While relays persist in low-complexity tasks, modern PLCs now centralize control logic, serving as the backbone of automated systems. Early PLC programming required manual input via physical control panels, a labor-intensive and error-prone process. The 1980s introduced computer-based programming (e.g., Siemens TIA Portal, Allen-Bradley RSLogix) [15.], enabling. Remote Programmability: Engineers modify logic and troubleshoot processes via internet-connected systems. Graphical User Interfaces: Simplify parameter adjustments (e.g., motor speed, timing cycles) without altering core logic, reducing training demands and human error. The Operational Benefits of the PLCs drive industrial efficiency through Scalability. Modular architecture expands automation networks seamlessly. Adaptability: Reprogrammable logic accommodates evolving production needs. Energy Efficiency: Real-time monitoring optimizes resource use, aligning with sustainability goals.

Integration with Industry 4.0: PLCs are important in smart manufacturing because they help different machines work together. For example, Siemens PLCs can adjust the speed of motors using Profinet protocols, which allows them to connect with devices such as Mitsubishi frequency converters. This teamwork shows how PLCs are used in Industry 4.0, a new way of making things that use data to improve accuracy and flexibility. [15]

2.5 Programming languages

Programming means writing instructions that tell a computer, or in this case, a control room substation, how to do specific tasks. These instructions, called a program, are written in a programming language. The choice of language depends on the type of computer and what we want to achieve.

Programming languages fall into two main categories: text-based and graphical. Text-based languages are flexible and can be used in many different areas. On the other hand, graphical programming languages are primarily used in automation because they make it easier to manage and monitor extensive automation processes.

Many manufacturers of Programmable Logic Controllers provide support for different programming languages. This is important because the choice of language depends on several factors, including the specific project's needs, the programmer's skills, and the complexity of the control system. [15]

2.5.1 Ladder Diagram

Ladder Diagram (LD) is a simple graphical programming language used in industrial automation. It looks like a ladder, with vertical lines representing power and horizontal "rungs" showing the logic, similar to how old relay systems worked. LD uses symbols for parts like switches, coils, and relays. It was first made for simple on/off operations but is still important today because it is easy to understand, especially for older systems that control relays, timers, and counters.

LD is significant for technicians who know relay logic because it is straightforward. However, it can struggle with more complex math and algorithms. Because of this, it is often used with other programming languages like Function Block Diagram to handle more complicated tasks. New versions of LD combine its easy-to-read format with more powerful computing abilities, which helps find and fix problems quickly. Even as technology changes, LD connects older relay systems with new digital logic, showing its lasting importance in learning and practical use. [15]

2.5.2 Structure Text

Structured Text is a type of programming language. It is used to write instructions for machines called programmable logic controllers, which help control various devices and processes. (PLCs), which are devices that help control machines and processes. It follows a standard called IEC. The language is similar to popular languages like Pascal and C, using clear and organized lines of code. The Structure helps programmers write instructions to repeat tasks and make choices based on certain conditions. This ability is important for handling complicated jobs that involve math, looking at data, and making fast decisions. The text-based nature of ST makes it accurate and flexible, which is different from graphical languages like Ladder Diagram, which shows instructions through pictures. Because ST follows a standard, it can work on different PLC systems from manufacturers like Siemens and Rockwell, making it easier to share and use code across different platforms. While ST might be challenging for technicians more familiar with visual programming methods, it connects traditional industrial systems with modern programming techniques. [15].

2.5.3 Instruction List

Instruction List (IL) is a basic programming language similar to assembly code. It uses simple commands like AND, LOAD, and STORE, which are easier to remember. The instructions are written in a straight line, one after the other. This

helps control devices accurately and work directly with hardware. IL is designed to be simple and uses very little memory, making it fast. Because of these features, IL is great for quick tasks or for devices that do not have much memory. Although IL is easy to write, it can be hard to read, making it difficult for many people to learn. Because of this, most people today use visual programming languages like Ladder Diagram or Function Block Diagram for automation tasks. However, IL is still used in specific areas, like maintaining old systems, developing firmware, and requiring precise timing. Instruction List strikes a balance between efficiency and ease of use. It remains important in places where performance is more important than making it easy for developers to understand. [15].

2.5.4 Function Block Diagram

A Function Block Diagram is a way to create computer programs using pictures. It shows how different parts work together to control machines or processes. This method uses blocks representing different functions, making it easier to understand how everything connects. reusable components are termed *function blocks*. These blocks encapsulate operations with defined input/output parameters, interconnected via directed lines to establish deterministic data flow and execution sequences. FBD's modularity enables engineers to decompose complex systems into subsystems for independent design, testing, and integration.

Here are some key benefits: Easy-to-understand displays of how data moves and how parts rely on each other. Reusing code with ready-made and custom blocks, like timers and communication tools. The ability to grow and organize systems easily by nesting blocks within each other for more significant projects. FBD is a type of programming that uses diagrams, which can make it less efficient for tasks that need much text or have a strict order, where languages like Structured Text are better suited. Nevertheless, FBD is very important for tasks that involve processing signals, controlling movements, and coordinating systems that are spread out. A case study implementing FBD for motor speed regulation and

safety interlocks demonstrated its efficacy in integrating analog signal conditioning, fault handling, and peripheral device communication. [15].

2.6 Communication Protocols

Data transmission is sending and receiving information between people or systems over communication networks. In the past, people used simple methods, like carrier pigeons, to send messages, but today, we mainly use digital technology, which allows faster and more efficient communication. Modern communication is organized by specific rules that help different systems work together smoothly. These rules are known as communication protocols, and they help ensure that data is sent correctly and appropriately formatted and that any errors can be fixed.

As we moved from older analog communication methods to digital ones, new protocols were developed to handle the complexity of extensive global networks. These protocols set technical standards for how data is shared and address issues like reliability, security, and the ability to grow with increasing demands. This section examines the key network protocols essential for today's digital communication. It explores how they work, how they have changed over time, and why they are vital for maintaining strong global information systems.

By studying these protocols, we can understand how they help standardize communication, promote technological growth, and add new technologies to existing networks. [16].

2.6.1 Fieldbus

Fieldbus systems are changing how we manage industrial automation. They use digital communication networks instead of using many separate wires to connect devices. This connects sensors, actuators, and controllers in a more organized way. With field bus systems, information can flow both ways, making the system quicker to respond. They also help lower the costs and make installation easier. Protocols like PROFIBUS, Modbus, DeviceNet, and Ethernet/IP help different old

and new devices work together. However, issues with different protocols and security risks are still important challenges.

Key Advancements and Protocols. PROFIBUS: Dominant in European manufacturing, it supports high-speed data transmission for complex automation tasks. Ethernet/IP: Integrates industrial automation with IT infrastructure via scalable Ethernet frameworks. DeviceNet: Leverages CAN technology for robust communication in harsh environments. Modbus: Maintains relevance due to simplicity and cross-platform compatibility.

Benefits and Challenges. Cost Efficiency: Reduced wiring and modular design, lower capital expenditures. Enhanced Diagnostics: Real-time monitoring minimizes downtime through predictive maintenance. Flexibility: Scalable networks adapt to evolving operational demands. We need to address some challenges. Different systems may not work well together, and there are cybersecurity risks. Because of this, we need to create standard rules, like those in the IEC 61158 series.

Fieldbus systems bridge operational technology (OT) and information technology (IT), aligning with Industry 4.0 objectives despite persistent interoperability hurdles. [16].

2.6.2 Modbus

Modbus is a communication protocol created in 1979 by a company called MODICON, which is now known as Schneider Electric. It is a foundational communication protocol enabling data exchange between industrial automation devices. Its open-source architecture, simplicity, and interoperability have established it as a de facto standard in Supervisory Control and Data Acquisition (SCADA). This system helps monitor and control equipment in factories and plants. Human-machine interfaces (HMIs) are the tools that allow people to interact with these systems and see important information. Moreover, building management systems. The protocol operates across three primary variants:

- Modbus RTU is a communication method that uses binary code. It checks for errors using CRC. This system works through connections like RS-232 or RS-485, and it is designed to be strong and reliable, even in noisy electrical places.
- Modbus TCP/IP: This version of the Modbus protocol works with Ethernet networks. It uses a system where one device requests information, and another provides it. This setup allows for fast communication over IP networks. Communication.
- Modbus ASCII sends easy-to-read letters and numbers, making it simpler to understand and check for problems, although it may be slower.

Modbus is a system that works well with both old and new machines because it does not rely on any specific vendor. However, it has some safety issues because it does not have built-in ways to protect data or check if users are valid. This can be a worry for companies that connect many machines. Despite these issues, Modbus is still essential for monitoring things in real-time and managing processes, especially when reliability and easy maintenance are needed. Its ability to connect older electromechanical systems with modern technology makes it valuable as industries move toward more advanced methods like Industry 4.0. [16].

3 Implementation of the project

3.1 Control Box Design and Functional Integration

The control box serves as a centralized enclosure for integrating critical components of an industrial automation system, including the variable frequency drive, programmable logic controller, circuit breakers, radio frequency interference filters, and relays. Its primary function is to orchestrate the seamless interconnection of these components, ensuring operational coherence and simplifying system maintenance. By consolidating hardware within a unified enclosure, the control box enhances accessibility, reduces wiring complexity, and mitigates electromagnetic interference, a critical consideration in high-noise industrial environments. The control box is an essential part of any industrial

automation system, acting as a central hub for important components like variable frequency drives, programmable logic controllers, circuit breakers, radio frequency interference filters, and relays. Thinking of it as the brain of the operation, its main job is to connect all these components smoothly, ensuring everything works together efficiently and making maintenance easier.

By housing all this hardware within one enclosure, a control box makes it more convenient to access these components and helps declutter the wiring, which can often become quite complex. It also plays an important part in helping to lower electromagnetic interference, a significant concern in noisy industrial settings. Overall, a control box simplifies industrial systems' setup and ongoing operation, making them more reliable and easier to manage.

3.2 Control Box Overview

The control box is designed to seamlessly integrate various components, making it a crucial element in modern industrial automation. Here is a brief look at its major features:

- **Variable Frequency Drive:** This component controls a motor's speed and torque by adjusting the input voltage and frequency, allowing precise performance.
- **Programmable Logic Controller:** Acts as the system's brain, executing control algorithms that orchestrate the entire automation process across different components.
- **Circuit Breaker:** These are critical for protecting the system, providing overcurrent protection to ensure that components are safe from electrical faults.
- **RFI Filters:** help reduce electromagnetic interference, ensuring that the system meets the necessary IEC standards for electromagnetic compatibility (EMC).
- **Relays:** Relays greatly enhance the safety of the entire system by enabling low-power control signals to manage high-power circuits.

This setup promotes efficient communication between all parts, allowing for real-time data sharing and harmonized operation. As shown in (Figure 1).

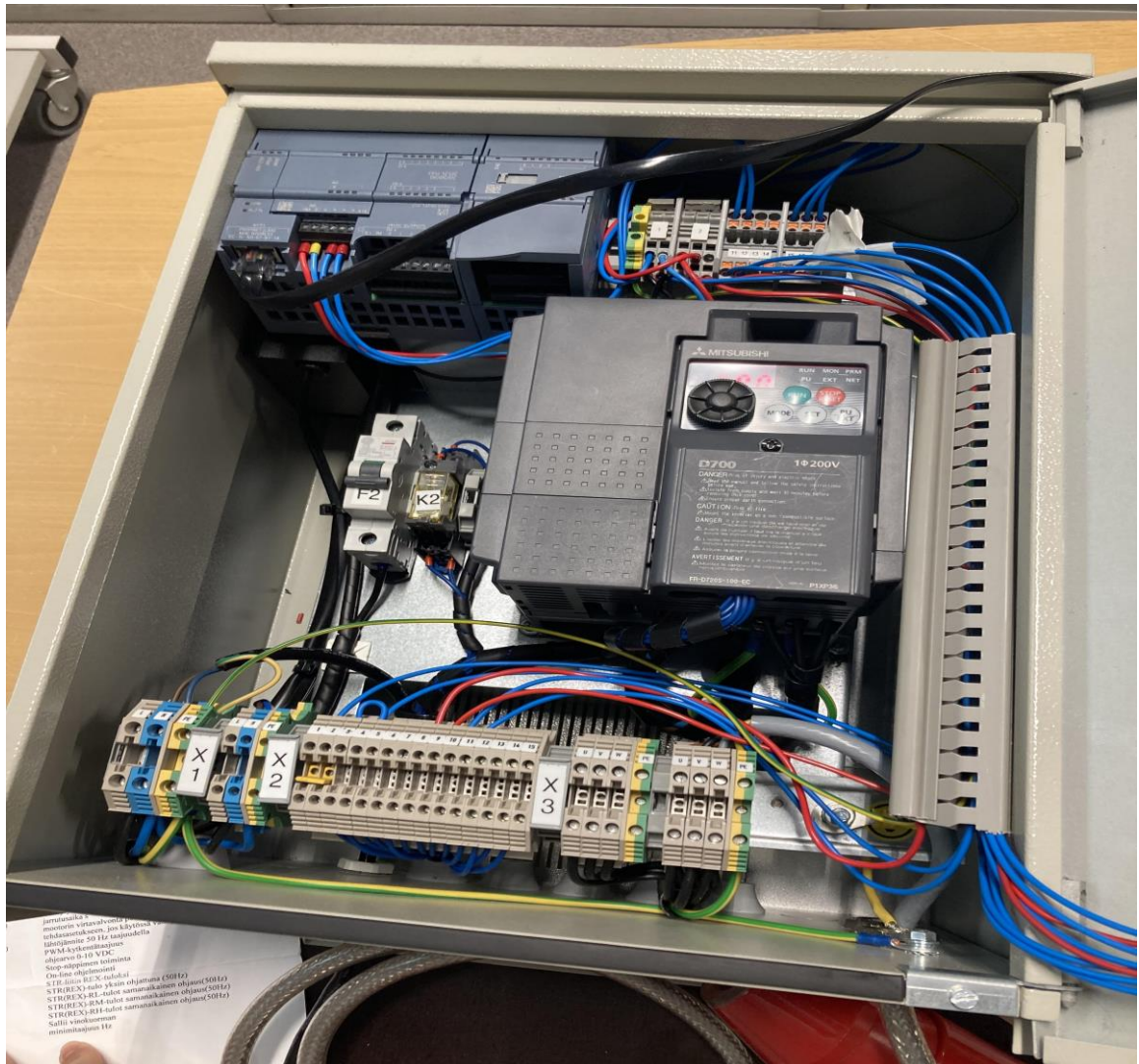


Figure 2. Electrical control Box.

3.3 Frequency Inverter Manual Configuration

Setting up the Mitsubishi frequency inverter correctly ensures it operates effectively with the motor and meets our needs. Initially, we used the standard settings that came with the inverter. Then, we adjusted some settings to accommodate the specific load type and our desired outcomes. This section outlines the main settings we modified during the project and explains what each one does.

- Speed and Frequency Regulation
 - Maximum Frequency (Parameter 1): Set to 50 Hz, establishing the upper limit for motor output frequency and ensuring compliance with the motor-rated specifications [1].
- Multi-Speed Settings:
 - High Speed (Parameter 4): Set to 50 Hz when the RH terminal signal is active.
 - Medium Speed (Parameter 5): Adjust to 25 Hz during RM terminal activation.
 - Low Speed (Parameter 6): Assigned 38 Hz for RL terminal input.
- Extended Speed Selection (Parameters 179, 232–236): Enabled 15-speed selection via the STR/REX terminals, with auxiliary inputs (RL, RM, RH) locked at 50 Hz to prioritize safety during testing.
- Acceleration and Deceleration Timing
- Acceleration Time (Parameter 7): Set 3 seconds to minimize mechanical stress during motor startup.
- Deceleration Time (Parameter 8): It has been extended to 100 seconds to prevent voltage spikes and ensure smooth braking.
- Safety and Protection Mechanisms
 - Electronic Thermal Overload Relay (Parameter 9): Disabled (00) to align with external protection circuits.
 - Output Phase Loss Protection (Parameter 251): Deactivated (0) due to redundant safeguards in the PLC logic.
 - Base Frequency Voltage (Parameter 19): Fixed at 230 V to maintain consistent torque output at 50 Hz.
- Signal Interface and Control Logic
 - Analog Input Configuration (Parameter 73): Assigned 0 to enable polarity reversal for bidirectional speed control.
 - PWM Carrier Frequency (Parameter 72): Set to 5 kHz to balance switching losses and acoustic noise.
 - Terminal 2 Bias Frequency (Parameter 902): Calibrated to 25 Hz to establish a minimum operational threshold.

- System Diagnostics and Reset Protocols
 - Reset Selection (Parameter 75): Configured to 1 to permit remote reset via the PLC.
 - Extended Function Display (Parameter 160): Enabled simplified mode for real-time monitoring of critical parameters.

- The Transformative Impact of Parameter Configuration

The settings in this system help the motor work smoothly, even when the load changes. It follows specific international standards for adjustable-speed electric drives. The system is designed to perform well and last a long time by carefully controlling how fast it speeds up and slows down, using multiple speeds, and having safety features. If the usual settings are changed, like slowing down more gradually, the decision is made to protect the machine from damage and avoid electrical issues.

4 Project components in general

4.1 Totally Integrated Automation Portal

The work began with setting up a project in the Siemens Totally Integrated Automation (TIA) Portal, a comprehensive platform for managing industrial automation systems. Once I launched the software, the Project View interface greeted me. This interface is the central workspace where all hardware and software components can be configured.

To get started, I used the "Add New Device" function to bring hardware into the project. This feature allowed me to choose from various automation parts, such as controllers, Human-Machine Interface (HMI) panels, PCs, and motor drives. A crucial step in this process was carefully selecting a Programmable Logic Controller (PLC) that matched our project's specific technical needs. I focused on several important factors, including the device's article number, firmware version, and compatibility with other modules.

For this study, I opted for the Siemens SIMATIC S7-1200 series PLC, specifically the CPU 1212 DC/DC/DC model (article number: 6ES7 212-1AE40-0XB0), which operates on firmware version V4.4. This compact CPU was appealing because of its balanced features, offering digital I/O capabilities, modular expandability, and support for real-time industrial communication protocols. This made it a perfect choice for small to medium-sized automation projects.

I ensured the PLC was fully integrated within the TIA Portal environment during the hardware configuration phase. This was vital for ensuring that everything could communicate seamlessly, including the CPU, power supply modules, and any additional peripheral devices. Successfully setting up this foundation was an essential step, paving the way for the following stages of the project, which involved ladder logic programming and designing the HMI.

The Totally Integrated Automation portal (TIA Portal) programming tool enables logic programming (Simatic STEP 7), user interface design (Simatic WinCC), and frequency converter configuration (SINAMICS STARDRIVER). This results in a uniform user experience for logic, visualization, and operation, making it more user-friendly and eliminating the need to study multiple programs.

In addition, the equipment shares a common database, which streamlines diagnostics and communication, requiring older S7 300/400 series logic to be programmed using the TIA Portal environment, which comes with the Simatic Step 7 software. For the S7-1200 and S7-1500 series logic, a wide range of ready-made libraries can be downloaded, providing access to many different functions. The TIA Portal Step 7 V10.5 version was released by Siemens in 2008, with subsequent versions offering additional features and improvements. The latest version, V18, was released in late 2022. [17].

Both basic and professional versions of the Step 7 software are available, and both can be used to program S7-1200 series logic. I have used the TIA Portal version V16 because that is the version available on my computer and in the University laboratory.

4.2 SIMATIC S7-1200

Siemens introduced the Simatic S7-1200 logic series in 2009 to replace the older S7-200 series. This series is primarily used to automate small and medium-sized devices such as conveyor systems, packaging machines, and car wash equipment and to monitor and control machine safety functions. The more powerful and versatile S7-1500 series is recommended for large and demanding entities. With the increasing demand for automation, the S7-1200 series is popular due to its compact design, cost-effectiveness, and user interface. Additionally, the series offers easy integration with systems and ready-made libraries, making programming faster and more efficient. [17].

4.3 Mitsubishi VFD

The Mitsubishi Electric FR-D720S is a powerful and versatile variable frequency driver designed to control AC motors with precision and efficiency. Whether we need to adjust motor speed for conveyor systems, packing machines, air conditioning units, or industrial fans and pumps, this drive offers the flexibility to meet various application needs. It can handle small and large operations with a motor capacity ranging from 0.5 to 120 horsepower. The FR-D720S module delivers 3.7 KW of power and operates at a rated current of 16.5A, supporting a wide frequency range from 0.2 to 400Hz. This drive stands out because of its advanced control features, including soft-PWM and high carrier frequency PWM control, frequency jump operation, and multi-speed operation, ensuring smooth motor performance and energy efficiency. It also comes with digital and analog inputs and outputs, allowing seamless integration into an automated system. Built with multiple protective features, it ensures reliability and safety in demanding environments. Whether you are optimizing industrial machinery or improving energy efficiency in HVAC systems, the variable frequency driver offers a competent and reliable solution for motor control. [1].

5 Project progression

Having the right tools is essential to plan and execute a project successfully.

- Computer for planning and making electrical drawings.
- CADMATIC program, which is used to make electrical drawings.
- A multimeter is used to measure the voltage and test the continuity of all the wires.
- Electrical tools, such as a screwdriver, connect the wires and, if necessary, temporarily move some components out of the way.
- TIA Portal is a totally Integrated Automation system where I can program and simulate the program after commissioning it in an actual project.

5.1 Project management

5.1.1 Project Planning and Functional Specification

The project commenced with developing a functional specification document outlining the technical requirements and operational objectives for automating motor control via a Siemens Programmable Logic Controller (PLC). The primary aim was to design a system capable of regulating a three-phase induction motor using a Siemens S7-1200 CPU (1212C DC/DC/DC) with a Mitsubishi FR-D720S-100-EC variable frequency drive (VFD). The selection of these components was guided by their compatibility with the project's electrical schematics, scalability, and alignment with industrial automation standards.

5.1.2 Component Selection and Justification

The Siemens S7-1200 PLC (1212C DC/DC/DC) was chosen for its compact architecture, modular expandability, and suitability for small to medium-scale automation tasks (Table 2). Key specifications included 14 digital inputs, 10 digital outputs, and integrated PROFINET connectivity, enabling real-time

communication with peripheral devices. To interface with the analog control signals of the Mitsubishi VFD, an analog output signal board (AQ 1x12-bit) and an analog input module (SM 1231 AI 4x13-bit) were integrated into the PLC rack. These modules ensured precise voltage/current signal conversion, critical for accurate motor speed regulation.

The Mitsubishi FR-D720S-100-EC VFD was selected for its strong performance in variable-speed motor control applications. It is compatible with the PLC's analog output range (0–10 V DC) and has built-in overload and short-circuit protection safety protocols.

5.1.3 System Integration and Configuration

The hardware configuration involved establishing a bidirectional communication framework between the PLC and the VFD. The PLC's analog output module was mapped to the VFD's speed reference input, enabling the PLC to transmit speed setpoints. Conversely, the analog input module was set up to monitor the VFD's operational feedback signals, including motor current and fault statuses.

Network integration necessitated assigning the PLC a static IP address and an Ethernet node name, facilitating seamless data exchange within the local industrial network. The PLC's tag table was filled with predefined input/output (I/O) addresses, designating a 32-byte memory range for analog and digital signals. Tags were systematically labelled to improve code readability and enhance troubleshooting efficiency.

5.1.4 Control Logic Implementation

A Function Block (FB) for motor control was developed within the TIA Portal environment. It encapsulates forward-direction logic operation, speed ramping, and fault handling. This block utilizes the PLC's cyclic interrupt routines to guarantee real-time performance responsiveness, with linear interpolation algorithms defining motor acceleration/deceleration profiles.

5.1.5 Validation and Risk Qualification

The project adhered to a phased validation protocol, beginning with bench-testing individual components and progressing to integrated system trials. Potential risks, such as signal interference between analog modules and electromagnetic noise from the motor, were mitigated through shielded cabling and proper grounding practices.

(Table 2) summarizes the Siemens S7-1200 PLC's technical specifications, highlighting its suitability for the project's scope. (Figure 17) point out the system architecture, emphasizing the integration of the PLC, VFD, and motor within the automation framework.

This structured approach to project management underscores the importance of meticulous planning, component interoperability, and iterative validation in industrial automation systems. The methodology ensures operational reliability while providing a scalable foundation for future expansions.

To begin the project, I created a script matching my desired outcomes. This script will serve as the function for my plan. This project aims to run a motor through a Siemens programmable logic controller (PLC). We have chosen an S7-1200 CPU and Mitsubishi frequency converter FR-D720S-100-EC based on an electric drawing as part of the project plan.

The S7-1200 PLC CPU 1212C DC/DC/DC is suitable for this project.

As it is designed for small and medium-sized (Table) shown the plc specifications. Additionally, I need an analog output Single board AQ1*13bit and an analog module card.

The PLC has been connected to control and monitor a frequency variable driver, which bridges the phase motor and the PLC. The input and configuration of the variable speed (Frequency Inverter) control the forward direction of the motor.

Table 1. PLC specifications. [17].

SI	Description	Details
1	Dimensions H/W/D	100mm/90mm/75mm
2	Weight	370g

3	Number of I/O	10 inputs (8 DI and 2 AI) 6 digital outputs (DO)
4	Power supply voltage	24 DC
5	Program and data memory	75 KB

5.2 Assemble the project components.

In this part of the project, the first step is to assemble all the necessary components according to the electrical drawing. It is essential to ensure compatibility between the devices, including the Siemens PLC and Mitsubishi frequency converter. The power supply of both devices should be wired to a 24 DC power supply. Next, defining the inputs and connecting them to the PLC input pots is necessary. For instance, the selector switch can be reserved for the start and stop buttons, the emergency stop pushbutton (reset), the push button for increasing the frequency of the motor or the high-speed push button, and the minimum frequency push button decreases the frequency and slows down the motor speed, and a green lamp for the running step. A circuit breaker should also be assembled to shut down the system in an emergency. Before commissioning an actual project, the last step is to simulate the project to test errors and evaluate the results (Figure 2).

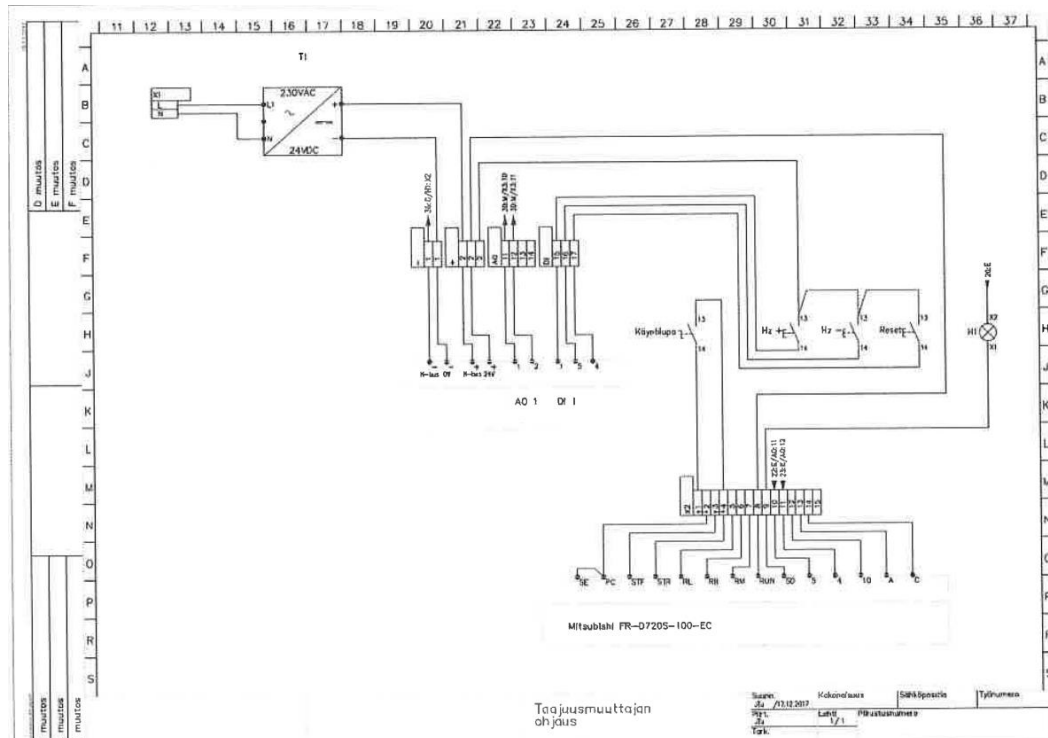


Figure 3. Electrical Wire Draw.

5.3 Project Setup: Software and Hardware Configuration

Following the selection of the Siemens SIMATIC S7-1200 PLC, the hardware configuration process commenced with the assembly of the PLC rack. The analog input module SM 1231 AI 4x13BIT (article number: 6ES7 231-4HD32-0XB0, firmware version V2.1) and the analog output module AQ 1x12BIT (article number: 6ES7 232-4HA30-0XB0, firmware version V1.0) were integrated into the rack via drag-and-drop functionality within the TIA Portal's device catalog. These modules were selected to accommodate the project's requirements for precise analog signal acquisition and output control. No additional peripheral devices were added to the PLC, finalizing the hardware configuration phase.

To enable seamless communication within the industrial network, the PLC was assigned a unique Ethernet node name and a static IP address, ensuring compatibility with networked devices and facilitating program uploads from the TIA Portal engineering software. The following configuration involved assigning I/O addresses to the variable frequency drive (VFD), a critical step for establishing bidirectional data exchange. This was achieved by embedding input

and output modules into the drive's device view and mapping specific memory addresses to the drive's functional parameters. These addresses were later referenced in the PLC tag table to standardize variable nomenclature and streamline data handling.

The PLC tag definition process, executed via the *PLC Tags* menu, allocated a memory range of 32 bytes for both input and output operations, adhering to the project's scalability requirements. Tags were systematically labeled to ensure intuitive differentiation between input (e.g., sensor feedback) and output (e.g., actuator control) variables. Address assignments were directly imported from the drive's device view, ensuring alignment between hardware configurations and software logic.

Finally, the Function Block for variable speed converter control was integrated into the project by importing a preconfigured block from the TIA Portal library. This block abstracted complex drive control algorithms into a modular component, enabling efficient implementation of speed regulation and fault management routines. (Figure 3) demonstrates the TIA Portal's Project View interface, highlighting its role in centralizing hardware configuration and project management. This structured approach underscores the importance of precision in industrial automation engineering, where hardware-software consistency directly impacts system reliability and performance.

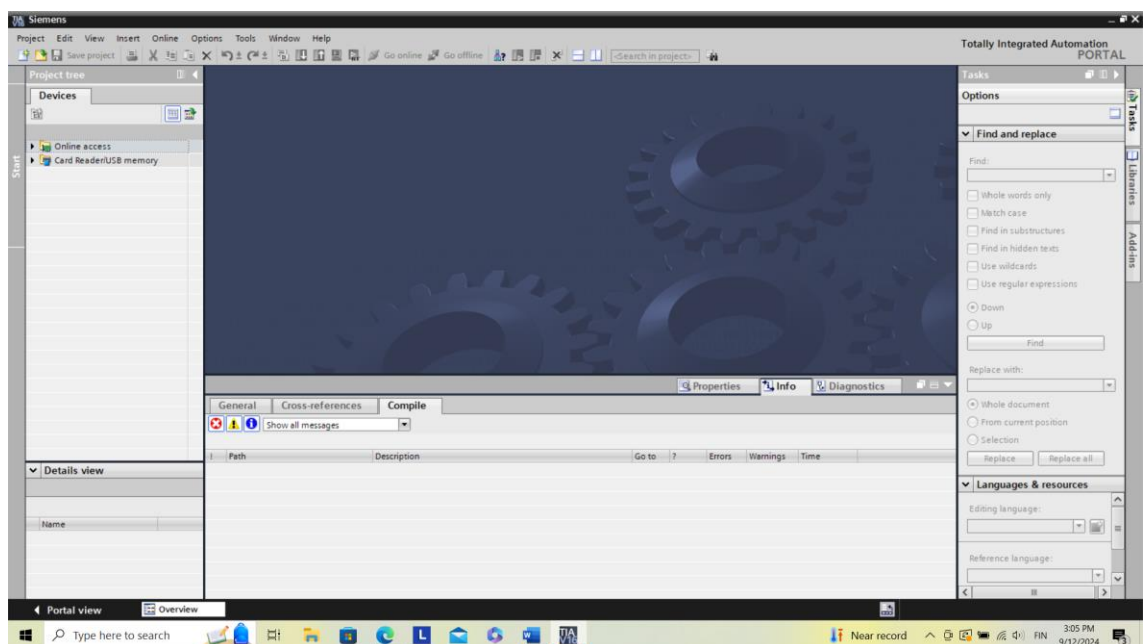


Figure 4. TIA Portal Project View.

Once the PLC rack configuration is complete, a crucial step is selecting the PLC. The analog input module SM 1231 AI413BIT, with article number “6ES7 231-4HD32-0XB0” and version number V2.1, was seamlessly integrated into the rack from the catalog. Likewise, the signal board analog output card AQ1 1x12BIT, with article number “6ES7 232-4HA30-0XB0” and version number V1.0, was added to the rack. All the devices were connected to the PLC, and the hardware configuration was complete.

The PLC requires an Ethernet name and IP address to function correctly with other devices on the network, enabling them to upload programs from the TIA Portal software. The variable frequency driver requires I/O addresses to be assigned to the module, which was accomplished by adding input and output modules in the device view of the driver; this assignment of modules automatically inputs and outputs addresses the drivers utilized in the PLC tags.

PLC tags were defined for input and output to facilitate data exchange between the devices. This procedure was executed within the PLC tags menu. Each device requires a specific range of bytes for input and output memory, but we allocated a broader range of 32 bytes for both in our project. Labeling the tags properly is crucial for easy differentiation.

The addresses for the tags were obtained from the drive device view, and the data exchange was completed. Next, the actual function block for managing the variable frequency was added to the project view by dragging it from the library.

5.4 The Project Commissioning

The main program, OB1, is the core of the project code that always runs continuously. All functions and function blocks in the main program are executed cyclically, starting from the first network, and proceeding to the final network defined in the program. This project incorporated three primary functions into the main program: The first network manages analog output operations in the code. The second network controls the variable frequency inputs and the timing of the

motor operations, and the third network is handling to emergency stop and program reset.

The first function block in the main program is used to convert the inputs, and the second function block is used to network outputs. The inputs become integer data type, and we used the `NORM_X` and `SCALE_X` functions to transform and change the data type from integer to real and from real to the integer; it normalizes the input value with the percentage value that allows us to play the output that controlled the variable frequency consequently control the speed of the motor.

The second function block, which is used for the timing and the change of speed from the first network to the third network, starts the process by switching on the green light, turning on the variable converter, setting up the movement forward or reverse time, and output the value of motor speed in the end network.

Simulating the project to test for errors and evaluate the results is important. This can be done using the simulation tools provided in the totally integrated automation portal TIA-Portal, which allows you to simulate the behavior of the PLC and frequency converter and identify any issues that need to be addressed. In this step, we can change all or a part of the code; we can change all the scripts and create a new program that can be more readable and practical in software and hardware. It is all based on the result of the project simulation. One of the benefits of the TIA portal environment is that it is more efficient and effective.

Before performing a site acceptance test on a variable frequency drive system, engineers often use a Programmable Logic Controller simulation to validate control logic and ensure smooth operation.

This software-based approach allows us to test and debug the program in a virtual environment before applying it to real hardware, helping to catch potential issues early and prevent costly errors. Simulating different operational scenarios allows the user to verify that the control logic follows the intended sequence, test safety interlocks like emergency stops and fault responses, and identify bugs before deploying it.

This process also allows fine-tuning of system parameters such as timing, cycle speeds, and sensor interactions, ensuring everything runs smoothly before field testing. Since most significant issues are addressed in the simulation phase, the

commissioning process is much faster and more efficient. Integrating PLC into SAT ultimately enhances reliability and safety, leading to more cost-effective and sustainable automation solutions. As industries continue to push for more intelligent, energy-efficient systems, mastering variable speed drivers and programmable logic controller simulations has become an essential skill for engineers. Whether new to this technology or looking to refining your expertise, embracing them can help create more reliable and efficient industrial solutions.

6 Summary

The project presented many challenges that required electrical and technical knowledge. As the work progressed, our understanding of programmable logic controllers and frequency converters grew exponentially, which will be beneficial in the future when working with similar equipment. However, the work was challenging in many respects. I was able to overcome the obstacles and complete the project on time. While there were some minor issues, such as a misunderstanding during the installation, the availability of work components significantly contributed to the project's timely completion. We resolved them through persistent searching and seeking advice from my supervisor, Kai Virta.

The completed project tasks enabled us to understand better the Siemens logic programmable, frequency converter, and programming. With these skills, we can design our hardware, software, and programs to control industrial equipment. These programming skills will be helpful in our future careers and can be applied to real-world industrial settings. Overall, the project was a success, and we gained knowledge to benefit us.

Although we faced some difficulties at the beginning of the project, such as finding GSD files, we resolved them with the help of the Mitsubishi factory. By the end of the project, we were able to achieve most of our goals, including the completion of the Siemens S7 logic controller, Mitsubishi frequency converter driver, and the intended design and assembly of the required equipment. Although the configuration guide tasks were completed later, they were introduced in due course.

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8 Documents

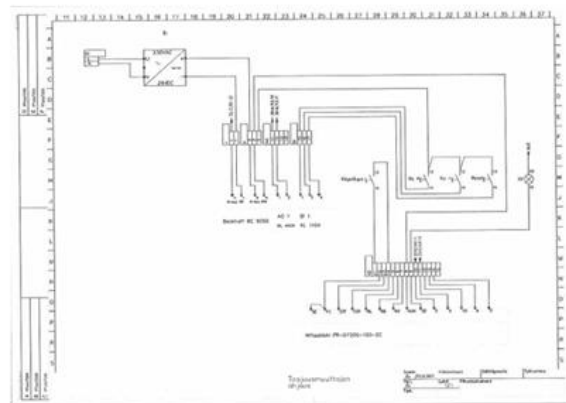
Mitsubishi Taajuusmuuttajan käyttöönnotto

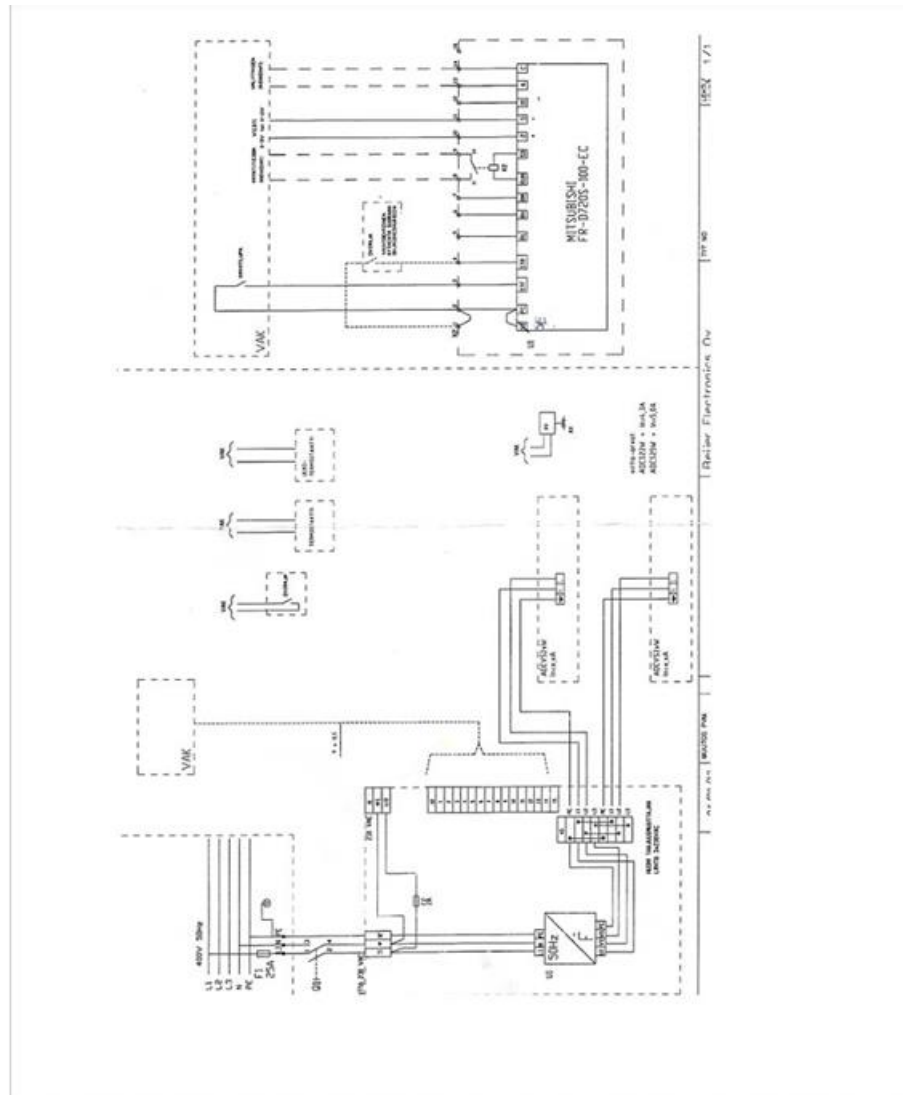
Työ tarkoitus on tutustua Siemens logiikkaan ja taajuusmuuttajan käyttöönnottoon.

Kytkennät

Suorita kytkennät jännitteettömänä.

Alla esitettyssä kuvassa on toimivan laitteen kytkennät. Kytke PLC:n riviliittimen johtimet kuvan mukaisesti (liittimet 11, 12, 15, 16, 17) Tarvitset yleismittarin piippaus toimintaa tähän. Älä irrota itse logiikkaan kytkettyjä johtimia.





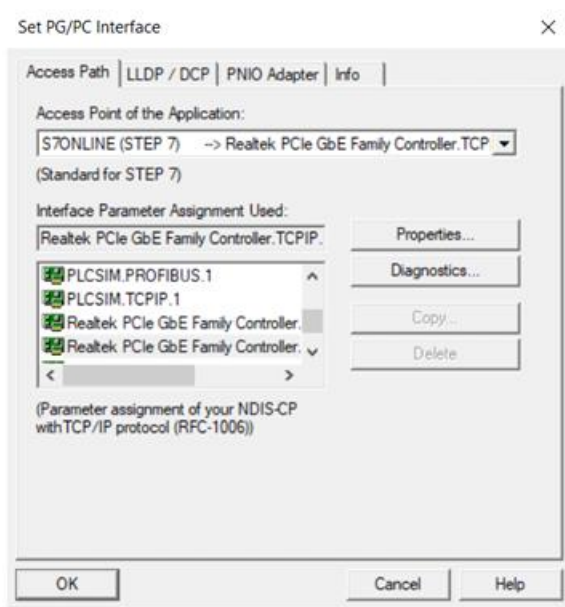
Taajuusmuuttajaan on valmiiksi asetettavat parametrit ja se on lukittu väärinkäytön estämiseksi. Etsi muutetut parametrit PrCH valikosta. Paina MODE nappia, kunnes PRM-valo palaa ja pyöritä rulla, kunnes näytössä lukee ja paina SET. Laite miettii hetken, jonka jälkeen rullaa pyörittämällä löytyy muutetut parametrit.

Tarkista parametrien asetusarvot ja kirjaa ne alla olevaa taulukkoon. Selvitä manuaalista kyseisten parametrien nimet ja selitä lyhyesti niiden tarkoitus.

 Lopuksi Palauta Laite MON Tilaan painelemalla MODE nappia.

Parametri	Asetus	Selitys
160	0	Parametrinäytön laajennus
1	50	Max. Taajuus Hz
4	50	RH 3/3-nopeus (50 Hz)
5	25	RM 3/3-nopeus (25 Hz)
6	38	RL 3/3-nopeus (38 Hz)
7	3	Kiihdytysaika s
8	100	Jarrutusaika s
9	00	Moottorin virtaavonta pois käytöstä, jätetään tehdasasetukseen, jos käytössä vain yksi moottori
19	230	lähtöjännite 50 Hz taajuudella
72	5	PWM-kytkentätaajuus
73	0	Ohjearvo <u>0-10</u> VDC
75	1	Stop-näppimen toiminta
77	2	On- <u>log</u> ohjelmointi
179	8	STR-liitin REX-tuloksi
232	50	STR(REX)-tulo yksin ohjattuna (50 Hz)
233	50	STR(REX)-RL tulo samanaikainen ohjaus (50 Hz)
234	50	STR(REX)-RM-tulo samanaikainen ohjaus (50 Hz)

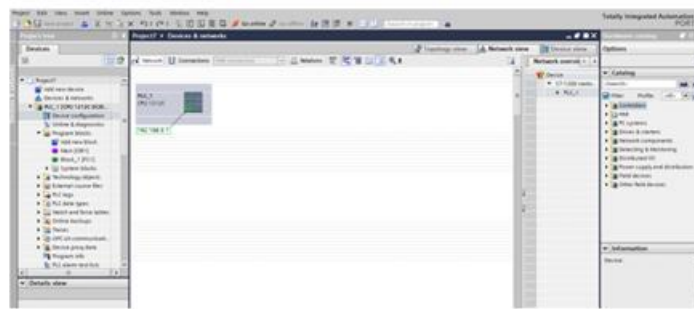
236	50	STR(REX)-RH-tulo samanaikainen ohjaus (50 Hz)
251	0	Salli vinokuorman
902 (C2)	25	Minimitaajuus Hz



Käynnistä TIA-Portal Manager

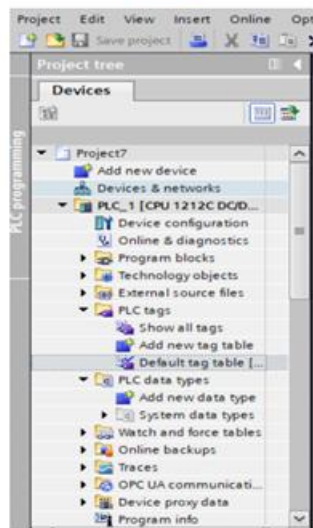
Muodosta yhteys laitteeseen. Laite näkyy verkossa nimellä Show address tables.

Jos reittiin luonti ei onnistu vaihda "Address info" kenttään muoto IP Address. Jos kysyy salasanaa tyhjä kelpaa.



Aseta system configuration tila.

Etsi I/O laitteet logikalta.

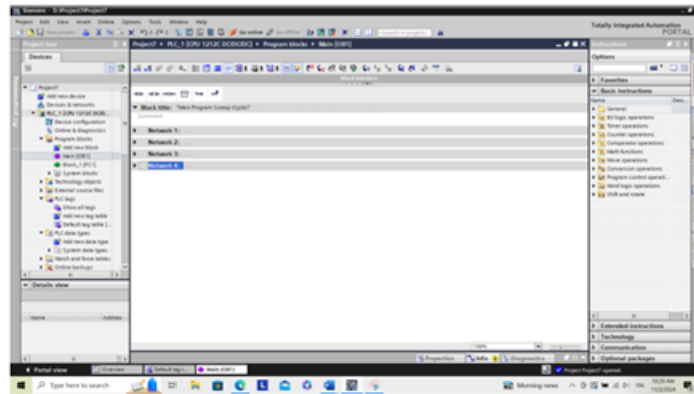


Tarkista löytyikö kaikki laitteet.

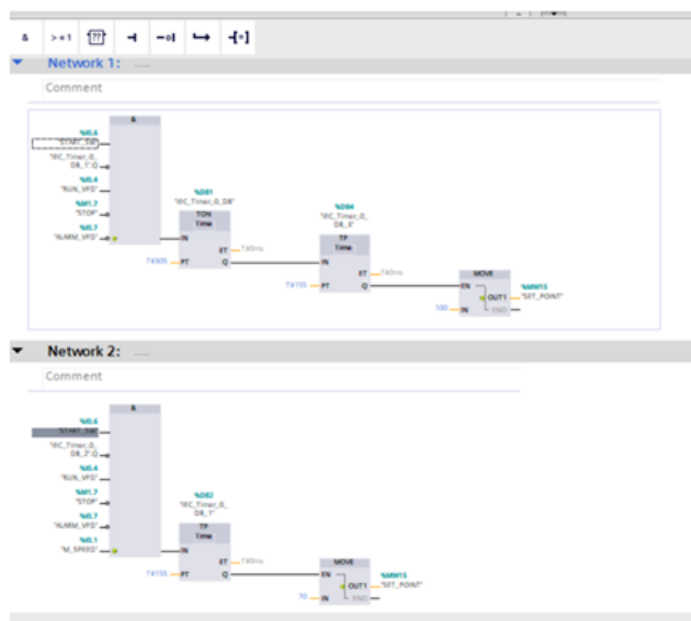
Listaa I/O laitteet ja niiden toiminnallisuudet.

Ohjelmointitehtävä 1

Käynnistä TIA Portal Control ja luo uusi ohjelma. Ohjelman "Project view", "Open existing project"

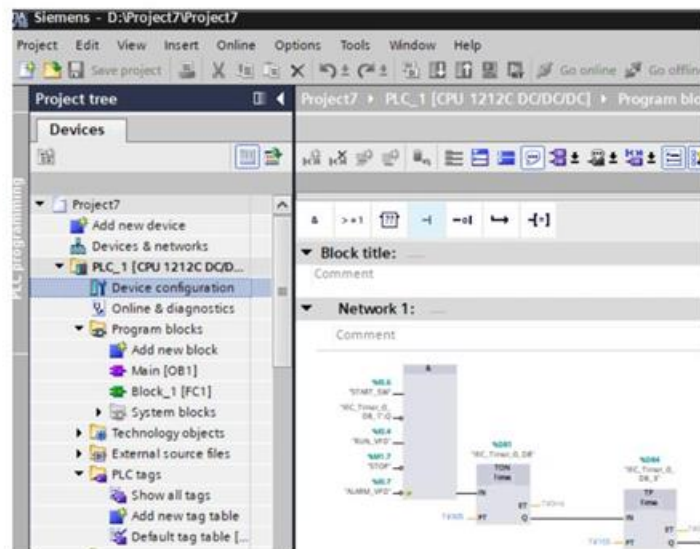


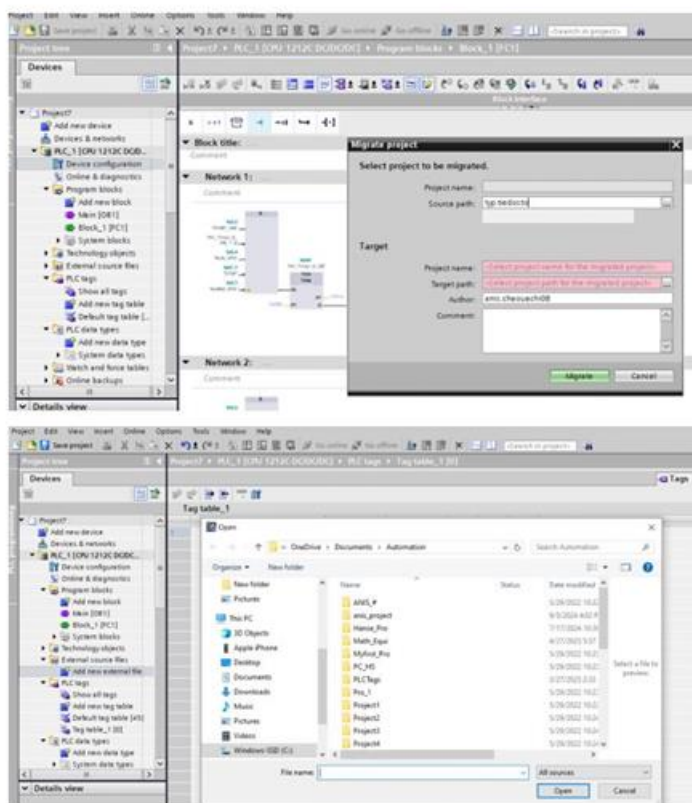
Tee ohjelma, jolla voidaan ohjata taajuusmuuttajan taajuutta askelmaisesti ylös ja alas. Suurin sallittu arvo on 50 Hz ja pienin 0 Hz. Ja reset napilla Taajuusmuuttaja arvo nollautuu. Ohjelma on toteutettavissa "AND", "CUTD" ja "MUL" FBD-lohkoilla. Output on 16-bittinen integer-muuttuja. Puskurin ylivuotoa ei saa tapahtua.



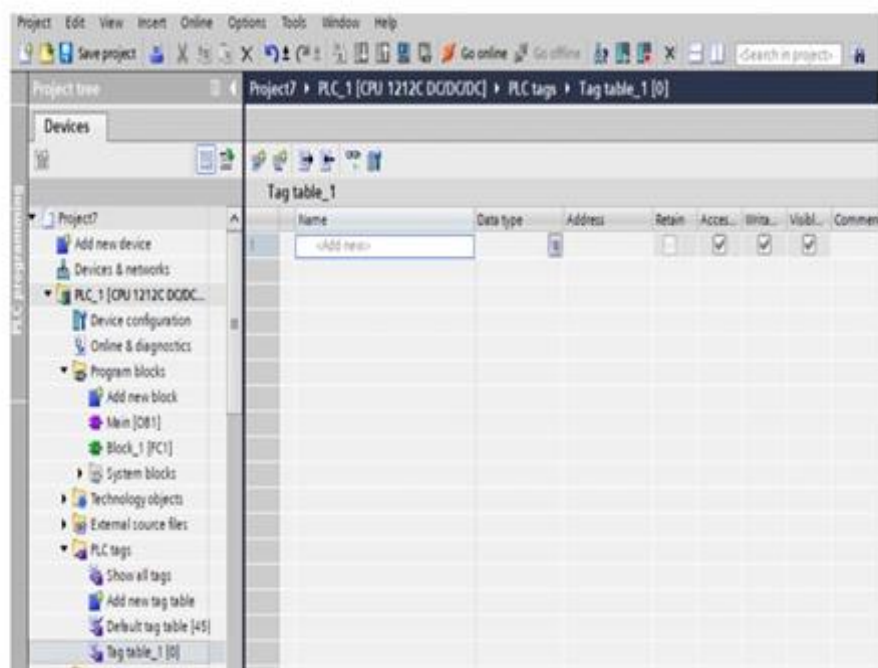
Ohjelman lataaminen logiikalle

Tallenna ohjelma. Käännä ohjelma valitsemalla Project valikosta build. Kun ohjelma kääntyy virheettömästi, pitäisi ohjelman tallennuskansiosi löytyä-tiedosto. Jos ei löydy voit kokeilla "rebuild" project valikosta.





Kun ohjelma kaännetty .typ tiedosto logiikalle, linkitetään ohjelman muuttujat I/O muuttujiin seuraavasti:



Tässä on linkitetty output muuttuja. Linkitä digitaaliset inputit samalla tavalla oikeisiin ohjelma muuttujiin.

Muista aktivoida uusi konfiguraatio TIA Portal ohjelma kohdasta "Device configuration".

PLC Controllin online valikosta "Program blocks", "Main [OB1]", "compile", "Download to device". Tämän jälkeen valitse "Go Online"

Testaa että ohjelma toimii oikein.

Ohjelmointitehtävä 2

Tee ohjelma joka nappia painamalla suorittaa seuraavan sarjan toimintoja:

1. Käynnistää moottorin täyteen vauhtiin 15s ajaksi
2. Aja moottoria 15s 70% nopeudella
3. Aja moottoria 15s 35% nopeudella
4. Moottori pysähtyy

Toeuta ohjelma haluamallasi tavalla.

Vinkki: Ohjelma on toteutettavissa FBD kielellä seuraavilla: TP, TON, BOOL_TO_INT, MOVE, NORM_X, SCAL_X. Kaikki tarvitaan useampia kappaleita ohjelman toteutukseen.

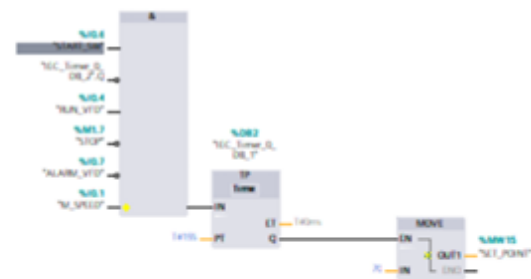
Network 1:

Comment



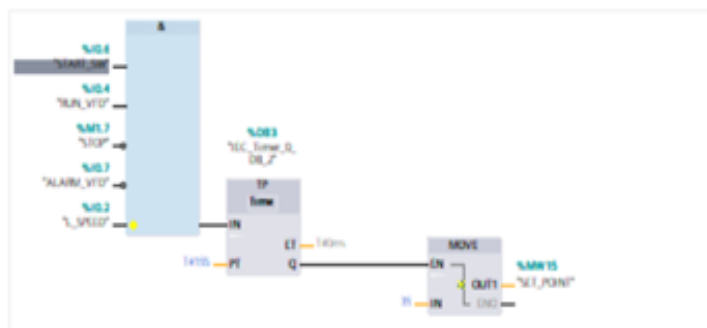
Network 2:

Comment



Network 3:

Comment



Network 4:

Comment

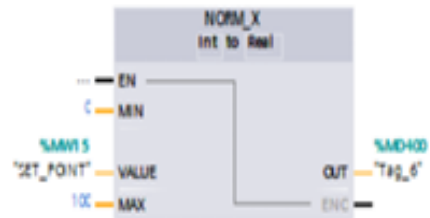


Block title: "Main Program Sweep (Cycle)"

Comment

Network 1: _____

Comment



Network 2:

Comment



Network 3: _____

Comment

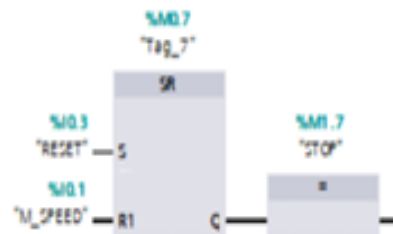
Network 3:

Comment



Network 4:

Comment



Network 5:

Comment