Modbus Based Smart Energy Tracking and Control and System

KON 4902 Control & Automation Engineering Design II

Final Report

Author

Kürşat Döşkaya
Kenan Selçuk
Burak Uğur
SID: 040200512, 040200509, 040170140

Supervised by

Dr. Onur Akbati

Submitted in fulfillment of requirements for the degree of
Bachelor of Science in Control & Automation Engineering

Department of Control and Automation Engineering
Istanbul Technical University
2025

The following text is only an example. Write your dedication sentence(s) here.

"...to my loved ones...."

"The supreme guide in life is knowledge."

Mustafa Kemal Atatürk, 19∞

"At times, our own light goes out and is rekindled by a spark from another person. Each of us has cause to think with deep gratitude of those who have lighted the flame within us."

Albert Schweitzer, 19XX

"Feeling gratitude and not expressing it is like wrapping a present and not giving it."

William Arthur Ward, 19XX

Abstract

This project presents the design and development of an intelligent energy monitoring and control system based on MODBUS communication protocol and Programmable Logic Controller (PLC). The aim of this study is to reduce unnecessary energy consumption, increase energy efficiency and ensure sustainable energy use in industrial environments by combining real-time monitoring, control algorithms and automation infrastructure.

The system collects real-time energy data via MODBUS from sensors integrated with machines such as DC motors and conveyor systems and transmits it to the PLC for analysis. Based on this data, control decisions are made using algorithms such as PID and LQR to optimize energy usage while maintaining system performance and safety. Factory IO software is used with Simulink and MATLAB to simulate the factory environment and validate the control strategy.

Mathematical modeling and dynamic simulation of a brushless DC motor were performed to evaluate the energy behavior under different conditions. The model includes electrical and mechanical parameters and calculates torque, speed, efficiency, and energy consumption over time. Using a custom-built simulation setup, performance metrics such as motor efficiency and energy savings were analyzed.

The project addresses critical engineering design criteria such as energy efficiency, system robustness, communication protocol integration and user safety. Engineering standards such as IEC 61158, IEC 61131-3 and ISO 50001 are implemented to ensure industrial compatibility and reliability.

As a result, this project provides a viable and scalable solution for industrial energy optimization while also contributing to environmental sustainability and operational cost reduction.

Keywords : Automation, control, energy efficiency, industrial communication, MODBUS, PLC, smart energy systems.

Abstract in Turkish(Özet)

Bu proje, MODBUS iletişim protokolü ve Programlanabilir Mantık Denetleyicisi (PLC) tabanlı akıllı bir enerji izleme ve kontrol sisteminin tasarımını ve geliştirilmesini sunmaktadır. Bu çalışmanın amacı, gerçek zamanlı izleme, kontrol algoritmaları ve otomasyon altyapısını birleştirerek endüstriyel ortamlarda gereksiz enerji tüketimini azaltmak, enerji verimliliğini artırmak ve sürdürülebilir enerji kullanımını sağlamaktır.

Sistem, DC motorlar ve konveyör sistemleri gibi makinelerle entegre edilmiş sensörlerden MODBUS aracılığıyla gerçek zamanlı enerji verileri toplar ve bunları analiz için PLC'ye aktarır. Bu verilere dayanarak, sistem performansını ve güvenliğini korurken enerji kullanımını optimize etmek için PID ve LQR gibi algoritmalar kullanılarak kontrol kararları verilir. Fabrika ortamını simüle etmek ve kontrol stratejisini doğrulamak için Factory IO yazılımı, Simulink ve MATLAB ile birlikte kullanılır.

Farklı koşullar altında enerji davranışını değerlendirmek için fırçasız bir DC motorun matematiksel modellemesi ve dinamik simülasyonu gerçekleştirildi. Model, elektriksel ve mekanik parametreleri içerir ve zaman içinde torku, hızı, verimliliği ve enerji tüketimini hesaplar. Özel olarak oluşturulmuş bir simülasyon kurulumu kullanılarak, motor verimliliği ve enerji tasarrufu gibi performans ölçümleri analiz edildi.

Proje, enerji verimliliği, sistem sağlamlığı, iletişim protokolü entegrasyonu ve kullanıcı güvenliği gibi kritik mühendislik tasarım kriterlerini ele alıyor. Endüstriyel uyumluluğu ve güvenilirliği sağlamak için IEC 61158, IEC 61131-3 ve ISO 50001 gibi mühendislik standartları uygulanmaktadır.

Sonuç olarak, bu proje endüstriyel enerji optimizasyonu için uygulanabilir ve ölçeklenebilir bir çözüm sunarken aynı zamanda çevresel sürdürülebilirliğe ve operasyonel maliyet azaltımına da katkıda bulunuyor.

Anahtar Kelimeler : akıllı enerji sistemleri, endüstriyel iletişim, enerji verimliliği, kontrol, MODBUS, otomasyon, PLC.

Declaration of Originality

We, the undersigned students, declare that this report was entirely prepared through our own efforts and work. All sections of the report that rely on external sources have been explicitly stated and properly cited.

During the preparation of the report, AI tools were used solely for supporting tasks such as grammar corrections, writing adjustments, and formatting. No AI tools or external sources were used for content generation in any part of the report.

For projects involving teamwork, we confirm that the contribution percentages specified in the Individual Contribution Statement section at the end of the report are accurate and that all team members contributed to the project in alignment with these percentages.

The checklist accompanying this report has been accurately and completely filled out in accordance with the relevant instructions.

Signatures:

Name and Surname	**Student ID**	**Date**	**Signature**
[Kürşat Döşkaya]	[040200512]	[29.04.2025]	[+]
[Kenan Selçuk]	[040200509]	[29.04.2025]	[+]
[Burak Uğur]	[040170140]	[29.04.2025]	[+]

Copyright Declaration

The following text is only an example. Prepare according to your project/study.

Contents

List of Acronyms

The following text is only an example. Prepare according to your project/study.

List of Symbols

The following text is only an example. Prepare according to your project/study.

$+$	Addition Operator	
$-$	Subtraction Operator	
$\times$	Multiplication Operator	
$\sqrt{x}$	Square Root of x	
$\odot$	Foo Bar	
$\Leftrightarrow$	Bar Foo	
α	Alpha	
β	Beta	
a	distance	m
P	power	W ($\mathrm{J\,s^{-1}}$)
ω	angular frequency	rad

List of Figures

List of Tables

1 Introduction

Contents

Motivation

- **Background and Context:** The increasing demand for energy efficiency, sustainability and cost optimization in industry has increased the interest in smart energy management solutions. One of the basic building blocks of these systems is the real-time collection of process data using communication protocols such as Modbus. Programmable Logic Controllers (PLCs) provide a reliable infrastructure for processing this data and implementing control algorithms. In this context, monitoring and optimizing energy consumption is of critical importance not only in reducing operational costs but also in contributing to environmental sustainability goals. This project aims to develop an innovative solution in the field of energy management in a virtual factory environment by combining real-time data analysis and control algorithms.

- **Problem Identification:** Despite advances in automation, many industrial systems still face high operational costs and unnecessary environmental impacts due to inefficient energy use. Traditional energy management systems lack real-time data collection and advanced control mechanisms. This makes it difficult to detect abnormalities in energy consumption and to effectively execute optimization processes. Therefore, there is a need to develop intelligent systems that can perform

1

real-time data analysis and optimize energy use using control algorithms such as PID, supported by Modbus-based communication. This project aims to provide a solution to address these deficiencies in a virtual factory environment.

- **Significance of the Project:** This project integrates PLC infrastructure, communication protocols and real-time data analysis by developing a Modbus-based smart energy monitoring and control system. The aim is to optimize energy consumption, increase system stability and reduce operational costs by using real-time monitoring and control algorithms together. The solution developed in the study is being tested in a virtual factory environment and offers a scalable structure that can be easily adapted to different industrial applications. Thus, it is aimed to make a significant contribution to energy efficiency and environmental sustainability goals.
- **Personal and Academic Motivation:** This study is directly compatible with our academic background in Control and Automation Engineering, combining theoretical knowledge with real-time monitoring, control algorithms and simulation-based system design. Through this project, we aim to develop our competencies in industrial communication, PLC programming, Modbus protocol usage and energy management. We also aim to create a strong infrastructure for our future career plans by contributing to global goals in the field of energy efficiency and sustainability.

Design Criteria

- **Performance Requirements**
  - The system must operate with accuracy to optimize energy consumption by at least 10.
  - Real-time data monitoring time should be provided with a maximum delay of 1 second.
  - The system must operate with over 95 stability and 98 fault tolerance.
- **Technical Specifications**
  - Hardware and software to be used: Siemens S7-1200 PLCSim, Factory IO, Modbus communication,MATLAB.
  - Modbus
- **Feasibility and Constraints**
  - If implemented, the total system cost will be kept at a reasonable level.
  - Power consumption will be minimized; data acquisition and control units will support low power modes.
  - Hardware and software integration will be easy, making maintenance and expansion of the system practical.

- **Scalability and Flexibility**
  - The system will be modular and will allow for the integration of more sensors or different control algorithms in the future.
  - It will be designed with flexibility to adapt to different production facilities and virtual factory environments.
- **Safety and Reliability**
  - Security measures (password protection, user authorization) will be applied to PLC communication.
  - The system will be configured to switch itself to safe mode in case of communication interruptions.
  - Hardware components will be tested periodically to ensure reliability.es
- **Usability and Human Interaction**
  - User-friendly monitoring and data analysis interfaces will be developed for operators.
  - Easy and fast access to energy consumption and system status information will be provided.
- **Environmental and Sustainability Considerations**
  - Solutions that will increase energy efficiency will be preferred and carbon footprint will be minimized.
  - If implemented, care will be taken to select recyclable materials in the components used.

Literature Review

- **Previous Work:** In the first examples of energy monitoring and control systems, manual data collection methods and local control systems were used. With the development of industrial automation, data transmission with Programmable Logic Controllers (PLCs) and Modbus protocol became widespread. Developed by Modicon in 1979, Modbus protocol has gained an important place in energy management applications by providing standard and reliable communication between different devices. Modbus RTU and TCP/IP based solutions have rapidly become widespread, especially for real-time monitoring of energy consumption and data transfer in factories.
- **Related Studies:** In recent studies, energy monitoring and control solutions developed with Modbus-based PLC systems are frequently used. For example, in the Sönmez study, applications were developed for monitoring and managing energy data with Modbus-supported automation systems. In the study conducted by Çetin, it was shown that energy efficiency could be increased

by using control algorithms such as PID in motor systems. In addition, the ISO 50001 standard contributes to the continuous improvement-oriented structure of energy management systems.

- **Research Gap** When the existing studies are examined, it is seen that they mostly focus on monitoring energy data, and energy optimization applications with real-time control algorithms are limited. Although many systems perform the task of data collection, advanced control techniques for dynamic energy optimization are not integrated. This project aims to fill this gap by not only monitoring energy consumption, but also optimizing it by analyzing it in real time.

Contribution of the Study

- **Scientific Contributions**
  - A smart energy monitoring and control system integrated with Modbus communication has been designed.
  - A PID-based control approach has been selected for real-time data collection and energy optimization.
  - The developed system has been tested with Factory IO and Simulink-based comprehensive simulation studies in a virtual factory environment.
- **Technical Contributions**
  - A real-time data acquisition and control platform was attempted to be created using Siemens S7-1200 PLCSim.
  - A reliable communication infrastructure was attempted to be developed using TIA Portal software and Modbus protocol.
  - System performance; accuracy, data transmission speed and stability were examined in terms of the system.
- **Practical and Industrial Contributions**
  - An attempt has been made to develop a system that can be applied in a virtual environment for industrial energy management.
  - The system architecture has been designed to be easily adapted to a similar system in reality.
  - The developed solution serves the purpose of reducing energy costs and supporting sustainable production processes.
- **Academic and Educational Contributions**

  - A simulation-based work environment has been provided on control systems, industrial communication and energy management.
  - Practical application experience has been gained on real-time data management, communication protocols and control algorithms.
  - The study constitutes a new academic research to be conducted on energy monitoring and control systems.

- **Societal and Environmental Contributions**
  - It works to reduce the industrial carbon footprint by increasing energy efficiency.
  - The project works towards environmental sustainability goals by optimizing resource use.

Structure of the Report

This report is organized into several chapters, each covering different aspects of the study. A brief outline of each chapter is provided below:

- **Chapter 1: Introduction**
  - Provides background information and motivation for the study.
  - Defines the research problem and objectives.
  - Summarizes the structure of the thesis.
- **Chapter 2: Literature Review**
  - Reviews existing research and related works in the field.
  - Identifies gaps and limitations in previous studies.
  - Justifies the need for the proposed approach.
- **Chapter 3: Methodology**
  - Describes the theoretical foundations and mathematical models.
  - Explains the proposed method, framework, or system design.
  - Details the tools, software, and experimental setup used.
- **Chapter 4: Implementation**
  - Discusses the practical realization of the proposed method.
  - Provides details on system architecture, hardware/software implementation.

  - Highlights challenges and how they were addressed.

- **Chapter 5: Results and Discussion**
  - Presents experimental results, data analysis, and performance evaluation.
  - Compares results with existing approaches.
  - Discusses key findings and their implications.

- **Chapter 6: Conclusion and Future Work**
  - Summarizes the main contributions of the study.
  - Discusses the limitations of the work.
  - Suggests possible directions for future research and improvements.

2

Literature Review

Contents

The following texts are random and meaningless. Prepare according to your project/study by considering the following subtopics.

- Review existing research and related works in the field.
- Identify gaps and limitations in previous studies.
- Justify the need for the proposed approach.

Review existing research and related works in the field

As any dedicated reader can clearly see, the Ideal of practical reason is a representation of, as far as I know, the things in themselves; as I have shown elsewhere, the phenomena should only be used as a canon for our understanding. The paralogisms of practical reason are what first give rise to the architectonic of practical reason. As will easily be shown in the next section, reason would thereby be made to contradict, in view of these considerations, the Ideal of practical reason, yet the manifold depends on the phenomena. Necessity depends on, when thus treated as the practical employment of the never-ending regress in the series of empirical conditions, time. Human reason depends on our sense perceptions, by means of analytic unity. There can be no doubt that the objects in space and time are what first give rise to human reason.

2

Identify gaps and limitations in previous studies

As any dedicated reader can clearly see, the Ideal of practical reason is a representation of, as far as I know, the things in themselves; as I have shown elsewhere, the phenomena should only be used as a canon for our understanding. The paralogisms of practical reason are what first give rise to the architectonic of practical reason. As will easily be shown in the next section, reason would thereby be made to contradict, in view of these considerations, the Ideal of practical reason, yet the manifold depends on the phenomena. Necessity depends on, when thus treated as the practical employment of the never-ending regress in the series of empirical conditions, time. Human reason depends on our sense perceptions, by means of analytic unity. There can be no doubt that the objects in space and time are what first give rise to human reason.

Justify the need for the proposed approach

As any dedicated reader can clearly see, the Ideal of practical reason is a representation of, as far as I know, the things in themselves; as I have shown elsewhere, the phenomena should only be used as a canon for our understanding. The paralogisms of practical reason are what first give rise to the architectonic of practical reason. As will easily be shown in the next section, reason would thereby be made to contradict, in view of these considerations, the Ideal of practical reason, yet the manifold depends on the phenomena. Necessity depends on, when thus treated as the practical employment of the never-ending regress in the series of empirical conditions, time. Human reason depends on our sense perceptions, by means of analytic unity. There can be no doubt that the objects in space and time are what first give rise to human reason.

3

Methodology

Contents

The following texts are random and meaningless. Prepare according to your project/study by considering the following subtopics.

- Describes the theoretical foundations and mathematical models.
- Explains the proposed method, framework, or system design.
- Details the tools, software, and experimental setup used.

Describe the theoretical foundations and mathematical models

As any dedicated reader can clearly see, the Ideal of practical reason is a representation of, as far as I know, the things in themselves; as I have shown elsewhere, the phenomena should only be used as a canon for our understanding. The paralogisms of practical reason are what first give rise to the architectonic of practical reason. As will easily be shown in the next section, reason would thereby be made to contradict, in view of these considerations, the Ideal of practical reason, yet the manifold depends on the phenomena. Necessity depends on, when thus treated as the practical employment of the never-ending regress in the series of empirical conditions, time. Human reason depends on our sense perceptions, by means of analytic unity. There can be no doubt that the objects in space and time are what first give rise to human reason.

3

Explain the proposed method, framework, or system design

As any dedicated reader can clearly see, the Ideal of practical reason is a representation of, as far as I know, the things in themselves; as I have shown elsewhere, the phenomena should only be used as a canon for our understanding. The paralogisms of practical reason are what first give rise to the architectonic of practical reason. As will easily be shown in the next section, reason would thereby be made to contradict, in view of these considerations, the Ideal of practical reason, yet the manifold depends on the phenomena. Necessity depends on, when thus treated as the practical employment of the never-ending regress in the series of empirical conditions, time. Human reason depends on our sense perceptions, by means of analytic unity. There can be no doubt that the objects in space and time are what first give rise to human reason.

Detail the tools, software, and experimental setup used

As any dedicated reader can clearly see, the Ideal of practical reason is a representation of, as far as I know, the things in themselves; as I have shown elsewhere, the phenomena should only be used as a canon for our understanding. The paralogisms of practical reason are what first give rise to the architectonic of practical reason. As will easily be shown in the next section, reason would thereby be made to contradict, in view of these considerations, the Ideal of practical reason, yet the manifold depends on the phenomena. Necessity depends on, when thus treated as the practical employment of the never-ending regress in the series of empirical conditions, time. Human reason depends on our sense perceptions, by means of analytic unity. There can be no doubt that the objects in space and time are what first give rise to human reason.

4 Implementation

Contents

Discuss the practical realization of the proposed method

In this section, practical implementation of smart energy monitoring and control system using Modbus protocol and Programmable Logic Controller (PLC) will be discussed. The system was designed to perform real-time data collection, analysis and control functions via a simulation program in order to increase energy efficiency and optimize energy consumption. The aim of the project is to monitor, optimize energy use in industrial facilities and reduce environmental impacts.

The basis of the system is to transfer energy data received from sensors to a PLC via Modbus protocol and process this data to optimize energy consumption. Here, a production system was implemented in Factory IO environment and then the PLC code suitable for this system was tried to be written via PLC software. PLC collects and processes data from sensors and will undertake the task of activating the control algorithm to improve the energy consumption of the system. It was decided to implement PID (Proportional-Integral-Derivative) as the control algorithm considered in this project. Both the simple and effective structure of the controller and its compatibility with PLC were effective in this decision. The purpose of using controllers is to turn devices on and off or adjust their speeds as necessary in order to minimize energy consumption and maximize system efficiency. a The simulation of the system in a virtual environment was performed with Factory IO software. This software has the ability to model and simulate industrial automation processes in a 3D environment and can be integrated with PLC and other automation systems. The simulation allowed the system to be tested in the real world and allowed the system to be evaluated without implementing a real application, considering the time and cost calculations.

The PLC used in the project process is the Siemens S7-1200 model. This model has high compatibility with the Modbus protocol and is widely used in industrial automation systems thanks to its fast processing capacity and expandable structure. In this project, a virtual PLC provided by Siemens, known as the PLCSIM application, was used instead of a real PLC. In the study, v18 versions were used in both programs. PLC Siemens S7-1200 was preferred due to the convenience of operating the PID control block and its compatibility with other programs.

The structure of the system components will be detailed below:

Sensors::

In order to control energy consumption, energy-related information such as speed, position, current of energy consuming system components must be known by the user. In this system, there are a number of power consuming components in the simulation environment. These are components such as conveyor systems that enable the movement of products in the system, robot arm that changes the position and state of the product. The robot arm transmits data to the PLC via the enerModbus protocol and fulfills the energy monitoring function by providing instant data for each energy parameter.

Figure 4.1: e6b2-c Encoder

PLC (Programmable Logic Controller):

A control device used in industrial automation systems. Siemens S7-1200 PLC is a widely used model in such systems and is known for its high performance. PLC usually communicates with sensors, actuators and other devices to control various processes. Such controllers analyze incoming data, apply certain logical operations and send output commands to make the system work more efficiently. One of the most important features of Siemens S7-1200 PLC is its compatibility with industrial protocols such as Modbus TCP/IP and Modbus RTU. These protocols allow PLC to exchange data with different devices and systems, thus ensuring seamless integration between devices.

Figure 4.2: S7-1200 PLC

Communication Protocols:

Modbus is a communication protocol widely used in industrial automation systems. Designed to provide data transmission and communication between devices, this protocol allows data received from sensors to be processed securely and quickly, especially in PLC (Programmable Logic Controller) systems. There are different versions of Modbus; the most common of these are Modbus RTU (Remote Terminal Unit) and Modbus TCP/IP (Transmission Control Protocol/Internet Protocol).

In the Modbus RTU module, data is transmitted in digital format and communication is generally established over serial connections (such as RS-232, RS-485). This version is preferred in low-cost and simple systems because it has sufficient features in terms of speed and security. The RTU format provides error control and data verification mechanisms in each data frame, ensuring the security of data transmission.

Modbus TCP/IP, on the other hand, uses an Ethernet-based system and transmits data over the network using internet protocols. This version is preferred in larger systems, when a large number of devices need to be connected to each other. Modbus TCP/IP optimizes data communication in industrial automation systems by offering higher speeds and more device support.

Control Algorithms

PID controller is a control system widely used in industrial automation and engineering applications, and includes Proportional (P), Integral (I), and Derivative (D) components. These components are combined to minimize the error between the target value and the current value of a system. PID controller is generally used to control temperature, speed, pressure, and other physical quantities. The basic components of PID control are explained below:

Proportional (P): The proportional component produces a control signal proportional to the error. The error is the difference between the target value and the actual value. This term determines the response speed of the system. A high Kp (proportional gain) value allows faster response to the error, but an excessively large Kp value may cause the system to be unstable.

Integral (I): The integral component takes into account the accumulation of the error over time. This term increases the error reset ability of the system and is used to eliminate static errors. However, a very large Ki (integral gain) value may cause the system to oscillate.

Derivative (D): The Derivative component takes into account the rate of change of the error. This term allows the system to reach equilibrium more smoothly and quickly. The value of Kd (derivative gain) helps to reduce the oscillations of the system, but a very high value of Kd can create excessive sensitivity in the system

Provide details on system architecture, hardware/software implementation

4.2.1 Software Programs

Here, the software programs used in the project will be introduced first and their functions will be mentioned in the project. Then, hardware and software applications related to the system will be explained.

Many different software programs were used together in the system. What they are and their roles in the project are as follows:

- **Matlab:** MATLAB (Matrix Laboratory), is a powerful software environment used for mathematical computations, data analysis, engineering and scientific research. Developed by MathWorks in the late 1980s, this software is widely used in many areas such as numerical computations, data analysis, graphics, simulations and algorithm development.

MATLAB is a matrix-based software environment, which is one of its most powerful features. While it focuses primarily on processing numerical data, it offers advanced mathematical functions, graphical tools, and a user-friendly programming language. MATLAB is often used in areas such as engineering calculations, control systems, signal processing, image processing, machine learning, and artificial intelligence.

MATLAB has a large number of built-in functions and toolboxes. Users can develop customized solutions in different application areas. For example, Simulink is a tool used with MATLAB for simulations of dynamic systems. It also allows users to visualize.

This project includes electric motors that drive the movement of robot arms and conveyors. Matlab was used to create models of these DC motors in the system and to relate the relationships of various physical quantities to each other and to energy.

- **Tia Portal ve PLCSim:** TIA Portal (Totally Integrated Automation Portal) is a software platform developed by Siemens and provides integrated management of all components of industrial automation systems. This software allows users to program and monitor various devices such as PLC (Programmable Logic Controller), HMI (Human Machine Interface), motors, sensors. TIA Portal simplifies the software development, monitoring and maintenance processes of automation systems. Users can manage automation projects in an integrated manner through a single platform and accelerate the design process. This software is designed specifically for Siemens S7 PLCs and the Simatic product family and is widely used in production lines and industrial facilities.

  PLCSim is a simulation software that works integrated with Siemens' TIA Portal. This software allows PLC programs to be run in a virtual environment. PLCSim helps engineers verify their software by simulating software development and testing processes before using real hardware. This software is extremely useful in training and development processes, detecting programming errors and foreseeing the operation of automation systems.

  In this project, TIA Portal software was used to control the industrial production line simulation created in the Factory IO environment via a virtual PLC. This program written via the TIA portal was connected with the PLCSim selection from the drivers section in the Factory IO section and the inputs and outputs were matched and controlled. The program belonging to the project can be seen in detail in Appendix-1.

- **Factory IO:** Factory IO is a simulation program used to model, test, and train industrial automation applications. Factory IO is used to perform simulations of PLC (Programmable Logic Controller) based systems, thus ensuring that industrial automation systems are designed and tested correctly.

Factory IO includes devices such as a virtual production line, conveyor belts, robots, sensors, and actuators. These devices can be controlled with industrial protocols such as Modbus TCP/IP, allowing the user to test PLC programs without requiring real hardware. One of the biggest advantages of Factory IO is that it is compatible with industrial programming software such as TIA Portal or RSLogix 5000. This compatibility facilitates system integration and allows engineers to develop their software faster and more efficiently.

Factory IO is used not only for simulation and training purposes, but also for the development of robotic systems, system design, and pre-application testing in the field. Users can simulate various industrial scenarios and applications in the software and increase the efficiency of the system by performing tests on these simulations. In addition, the software provides the necessary tools for users to test PLC programs, perform system verification, and perform performance analysis.

As will be explained in detail in the following sections of this project, a simulation environment was created in the Factory IO environment where two parts will be combined. Then, the program was connected to the virtual PLC via PLCSim and the process was controlled from there.

4.2.2 Created Project Environment

This project includes a simulation program that involves producing two different parts that have key-lock compatibility with each other and then integrating them with a robot arm. As mentioned before, Factory IO, which produces a prototype of the real industrial world, was used as the simulation program. Figure 4.3 below shows the empty world of the Factory IO program.

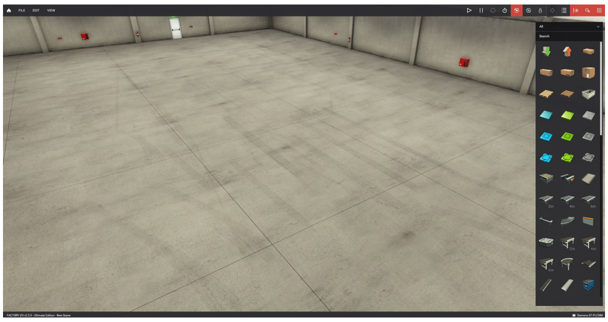


Figure 4.3: Factory IO starting environment

As explained above, the project includes a simulation program that combines two parts. Below is a detailed examination of the system and an explanation of its working logic.

Below is the front view of the simulation system created in Figure 4.4.

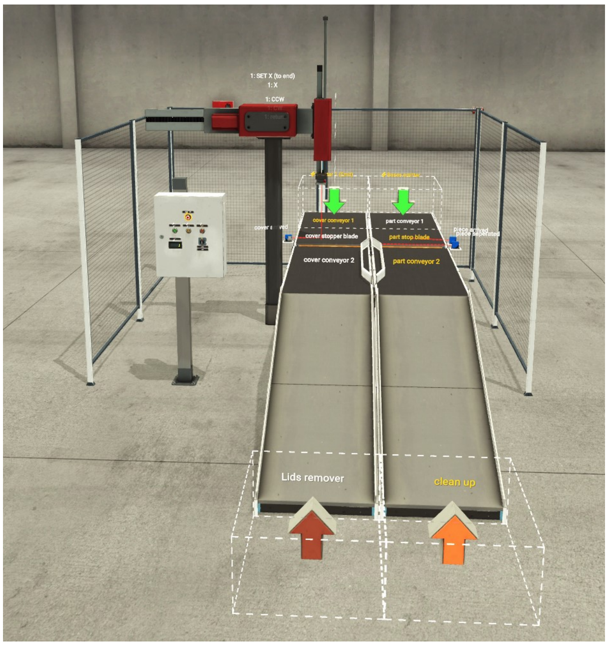


Figure 4.4: Front view of the created system

The right view of the simulation system is shown in Figure 4.5.

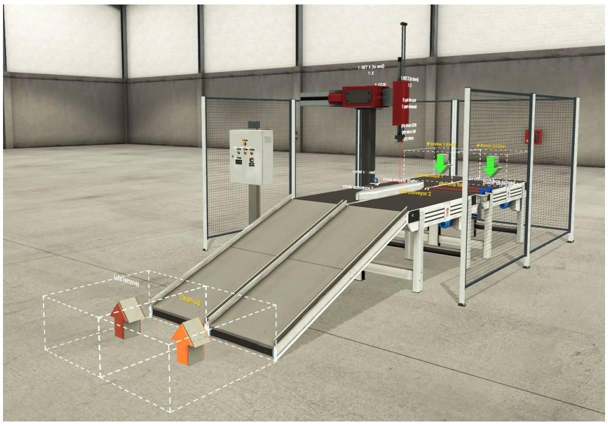


Figure 4.5: Right view of the created system

The left view of the simulation system is shown in Figure 4.5.

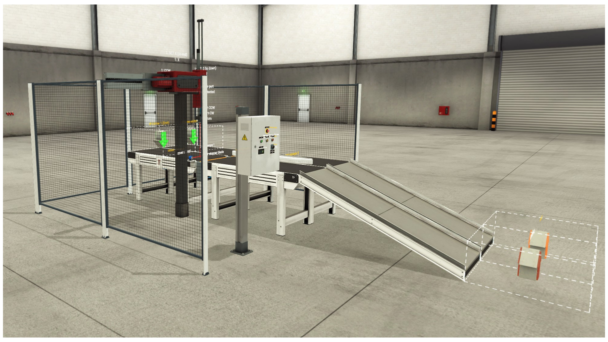


Figure 4.6: Left view of the created system

- **Working Principle of the System:**

1. **First stage:** When the start button is pressed while the emergency stop button shown in Figure 4.7 is closed, the part and cover conveyor shown in Figure 4.8 will start working.

2. **Second stage:** When the created part and the cover are detected by the diffuse sensors seen in blue on both sides, the blades will lift up and the progress of the products on the belt will be stopped.

3. **Third stage** The robot arm will come into play and, as seen in Figure 4.9, it will pick up the cover according to the values set for it, place it on the body and drop it.

4. **Fourth stage** After the parts are combined, the blade in front of the part will lift and the combined product will continue on the conveyor.

5. **Fifth stage:** Finally, the product that has completed its movement on the conveyor will slide down from the platform and be removed as seen in Figure 4.11.

Figure 4.7: Board with buttons

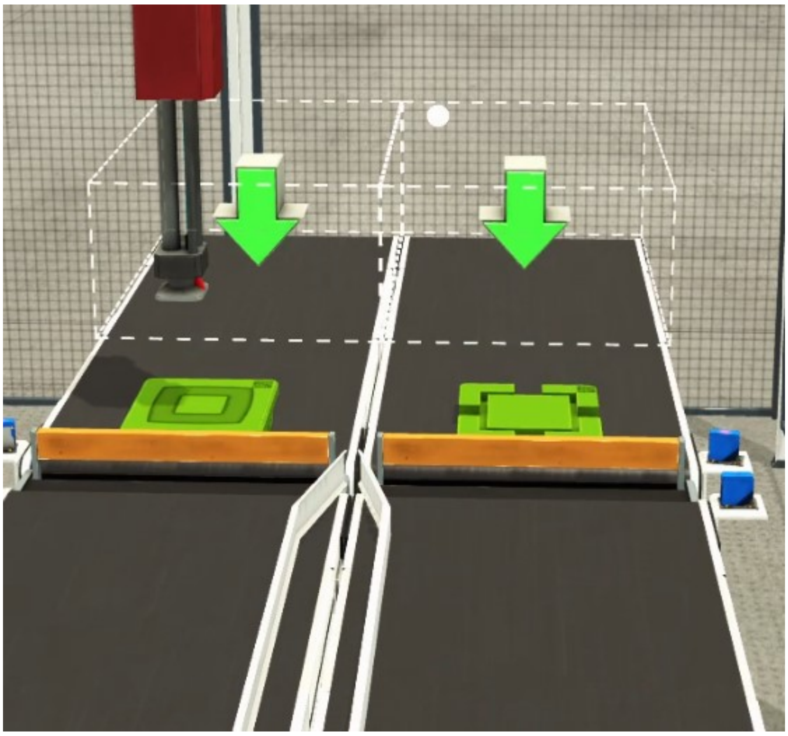


Figure 4.8: Creating parts and covers

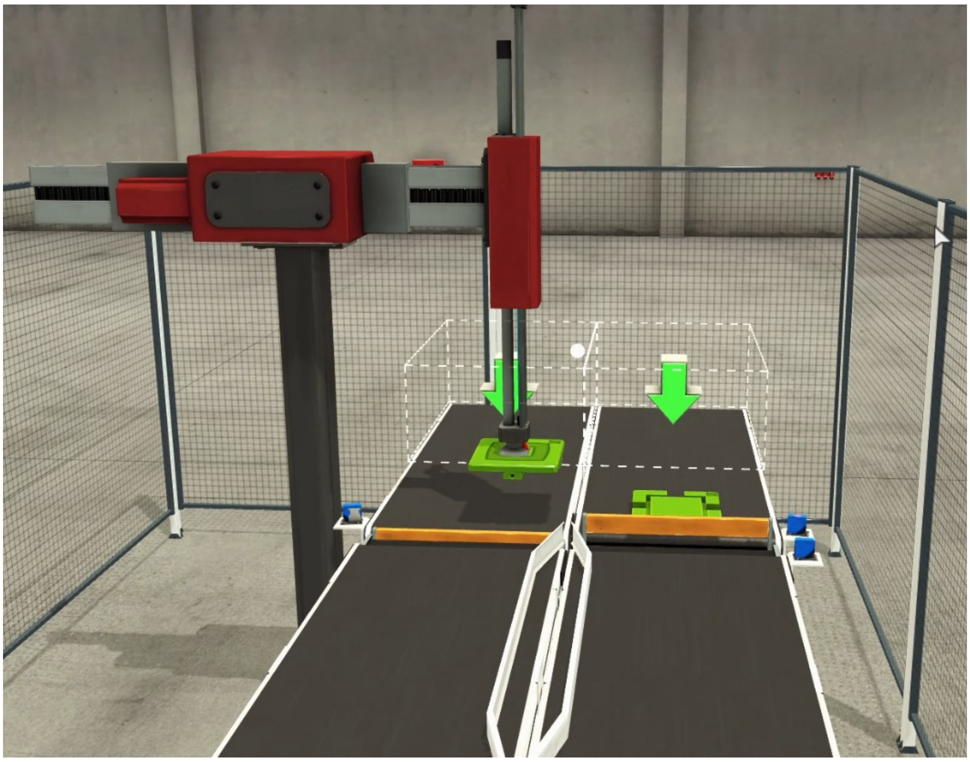


Figure 4.9: Robot arm moves the cover to the body

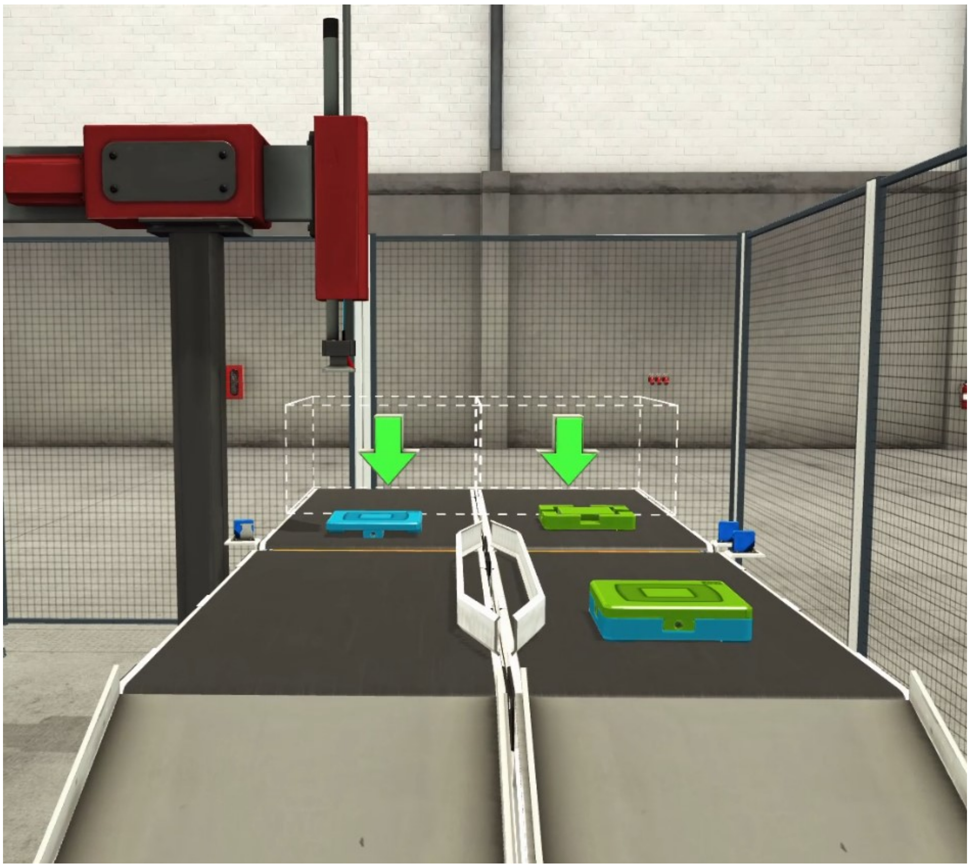


Figure 4.10: After the blades are opened, the produced part moves forward on the conveyor.

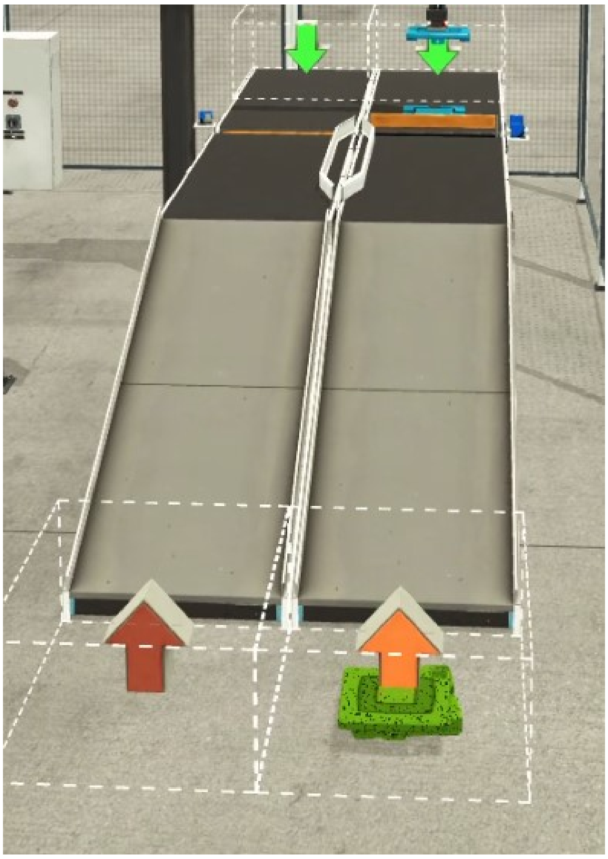


Figure 4.11: The manufactured part completes the conveyor and reaches the final stage.

All of these processes above are programmed via TIA Portal software and the inputs and outputs are placed in the same positions in the PLC and Factory IO software. Below is the configuration of inputs and outputs in Factory IO according to PLCSim. The TIA Portal program that enables the operation of the system is presented in detail in Appendix-1.

Figure 4.12: S7-1200 PLCSim driver settings

Highlight challenges and how they were addressed

This project first includes the creation of an industrial production system in the Factory IO environment and the control of this system with a PLC. Then comes the determination and modeling of energy consumption parts. It is aimed to replace the parameters obtained from the industrial system and related to energy consumption in the model and operate with a PID controller at maximum efficiency.

In the part of the project so far, the system has been created, controlled with a PLC, energy consumption elements have been determined and energy-based modeled. The problem encountered is that the energy and parameters of the conveyors and robot arm located in the production facility and causing energy consumption cannot be obtained. The main problem causing this is that the Factory IO program does not have sensors such as an energy analyzer or encoder that will give the rotation speed of the motors directly. In addition, there is no data regarding the type of these motors or the simulation parameters. In other words, only the energy-related parameters of these two components need to be determined in order to complete the project. After this is done, the created model will be replaced and control will be provided with a PID controller. Research on this is ongoing.

Apart from this, while creating the system in Factory IO, a problem was encountered in which the system worked without pressing any buttons, and this was solved with the added emergency stop button. Apart from this, some minor system failures were experienced and easily solved.

In this study, it was aimed to transfer the energy data of the conveyor system to the PLC using the Factory I/O simulation software. However, as a result of the tests, it was not possible to transfer the data related to energy consumption directly to the PLC in the simulation environment at the expected level. Due to these technical limitations experienced during the implementation process, it was decided to evaluate the possibility of continuing with the SCADA (Supervisory Control and Data Acquisition) system, which offers a more stable and measurable structure in the monitoring and control component of the project.

SCADA systems provide high-level visualization, data collection and central control in industrial automation and energy monitoring projects; enabling real-time process monitoring. In this context, parameters such as the operating status of the conveyor system modeled in the Factory I/O environment, the triggering time of the motors, and the active times of the loads in the system can be digitized via the PLC and transferred to the SCADA screen. By using a Ladder diagram to be developed within the PLC, the operating times of the motors can be measured with counters or timers (TON blocks) and the approximate energy consumption can be calculated based on these values. For example, a certain fixed power factor is defined for each motor and the energy consumption data is obtained by multiplying it by the motor operating time. When this data is transferred to the SCADA system, both instantaneous energy consumption and total cumulative consumption can be monitored graphically via the user interface. In addition, thanks to the alarm and reporting features of SCADA; automatic warning systems can be created for situations such as exceeding energy limit values and periodic consumption analyses can be reported. Thus, a realistic and traceable energy management system can be established in the light of the data obtained from the processes created in the simulation environment without using a physical energy analyzer in the field. This approach allows students to develop both PLC programming and SCADA application development competencies in an integrated manner.

5 Simulations, Results and Discussion

Contents

Present experimental results, data analysis, and performance evaluation

As mentioned before, the system is designed and simulated in the Factory IO environment. Since the program is a simulation of a factory environment, it cannot be expected to be fully compatible with the real world. Due to modeling errors and simulation errors, the system cannot be expected to work at an optimal level.

A part and cover clamping project coded with PLC and implemented in the simulation environment works successfully in the simulation. From time to time, due to programmatic errors or sensor detection programs, it has been observed that although the parts are programmed to be the same size and their midpoints overlap, the midpoints do not overlap and different parts are clamped.

It has been determined that the encoders planned to be used for the determination of energy-related quantities such as speed and position of the system are not available in the simulation environment. The main reason here is thought to be that the program cannot reach the high-frequency data processing capacity of the encoders. At this point, the possibility of slowing down the system speed and programming a manual encoder or using a different tool for simulation is considered in future studies.

After the energy-related components of the motors are obtained, it is thought that the simulation can be performed by replacing the parameters in the currently ready DC motor model. Then, it is thought that a PID block design will be made in the Matlab software with the obtained data and then the coefficients found will be transferred to the program with the PID block in the PLC.

In this way, the optimization of the system's energy saving will be provided by working together with many programs on energy-consuming motors.

Compare results with existing approaches

In our study, the system architecture is based on a PLC-based structure, and energy consumption is monitored in real time; data processing is performed with PLC and a virtual modeling of physical systems is provided using Factory IO software. In this structure, control and monitoring operations are carried out directly through the interaction between PLC and Factory IO. Within the scope of the software platform, PID control applications are implemented for users and data visualization is provided. In the "Development of a Real-Time Energy Monitoring Platform" study, data is received from the energy analyzer using the RS485 communication protocol and a basic level graphical data monitoring service is offered to the user via an interface developed with the DELPHI language; there is no virtual modeling or simulation integration in this project. In the "Industrial IoT-Based Energy Monitoring System Using Data Processing at Edge" study, the system architecture is based on the edge computing approach, data is collected on a local server and analyzed via a JavaScript-based data processing engine and presented to the user with an advanced dashboard interface; in addition, automatic e-mail notification mechanisms are also included in the system. However, there is no simulation or modeling infrastructure representing the physical process in this study. In this context, although the studies examined aim to monitor energy, they show significant differences in terms of system architectures, data processing methods and software platforms.

Discuss key findings and their implications

The important negative finding, as mentioned before, is the difficulty in transferring data to the PLC due to the encoder problem in the simulation program. Although other processes were ready, the energy-based control of the system could not be performed due to this problem.

The important positive findings are that industrial processes can be successfully performed in the simulation environment. Conversely, it is highly probable that the processes implemented in the simulation environment can also be performed in the real world. If this is done, sensor problems can also be prevented.

6

Conclusion and Future Work

Contents

Main Contributions of the Study

Within the scope of this project, a real-time energy monitoring and control system integrated with a PLC using a Modbus-based communication protocol was developed. The modular architecture of the system allows for future expansion and improvement work. In addition, the design of the system using low-cost hardware that complies with industrial standards provided both economic efficiency and ease of application.

Limitations of The Work

The system developed within the scope of the project was limited to a specific PLC model and energy analyzer. The integration of the system with different brands and models of devices was not tested. In addition, the communication infrastructure was implemented only via the Modbus RTU protocol, and compatibility with other communication protocols (such as Modbus TCP/IP or OPC UA) was not evaluated. Real-time performance analysis was performed only on specific sample load scenarios.

Suggestions for Future Studies

In future studies, the system can be integrated with different communication protocols to increase its flexibility. In addition, more in-depth analysis of energy consumption data can be made possible by adding advanced data analytics algorithms. Redesigning the system to work on different hardware platforms and integrating it with cloud-based monitoring systems will also enable the project outputs to be transferred to wider areas of use.

Ethical Rules Compliance Statement

I recognize and accept the basic principles of engineering which stated below.

Name and Surname	**Student ID**	**Date**	**Signature**
[Kürşat Döşkaya]	[040200512]	[29.04.2025]	[+]
[Kenan Selçuk]	[040200509]	[29.04.2025]	[+]
[Burak Uğur]	[040170140]	[29.04.2025]	[+]

Engineers; they glorify and develop the integrity, honor and value of the engineering profession by using their own knowledge and skills to increase the welfare of humanity, by serving honestly and impartially to the public, their employers and customers, by striving to increase the ability and prestige of the engineering profession, by supporting the professional and technical unity of their disciplines.

- Engineers will prioritize the safety, health and comfort of the society while performing their professional duties.
- Engineers will only provide service in areas where they are authorized.
- Engineers will only issue objective and realistic reports.
- Engineers will act as reliable attorneys or assistants to the employer or client in professional matters and avoid conflicts of interest.
- Engineers will establish their professional reputation according to the requirements of their services and will not enter into unfair competition with other colleagues.
- Engineers will work to promote and develop integrity, honor and value of profession.
- Engineers will continue their professional development through their own careers and will provide opportunities for the professional development of engineers under their control.

I declare that the parst quoted from any source in this report are less than 15%, and the number of one-to-one quotations in paragraphs is zero.

Name and Surname	**Student ID**	**Date**	**Signature**
[Kürşat Döşkaya]	[040200512]	[29.04.2025]	[+]
[Kenan Selçuk]	[040200509]	[29.04.2025]	[+]
[Burak Uğur]	[040170140]	[29.04.2025]	[+]

IEEE Code of Ethics

IEEE CODE OF ETHICS: It will be added to the report as it is.

We, the members of the IEEE, in recognition of the importance of our technologies in affecting the quality of life throughout the world, and in accepting a personal obligation to our profession, its members and the communities we serve, do hereby commit ourselves to the highest ethical and professional conduct and agree:

1. to accept responsibility in making engineering decisions consistent with the safety, health and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;
2. to avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist;
3. to be honest and realistic in stating claims or estimates based on available data;
4. to reject bribery in all its forms;
5. to improve the understanding of technology, its appropriate application, and potential consequences;
6. to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;
7. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;
8. to treat fairly all persons regardless of such factors as race, religion, gender, disability, age, or national origin;
9. to avoid injuring others, their property, reputation, or employment by false or malicious action;
10. to assist colleagues and co-workers in their professional development and to support them in following this code of ethics.

Approved by the IEEE Board of Directors

August 1990

Individual Contribution Statement

This Interim Report/Graduation Project is the result of a collaborative research effort by **Project Group**, consisting of **Kürşat Döşkaya,Kenan Selçuk,Burak Uğur**. While the research was conducted as a team, each member contributed distinctively to different aspects of the study.

Team Contributions

Team members contributed in the following ways:

- [**Kürşat Döşkaya**]: Contributed to the establishment of the system in the simulation environment, PLC connections and modeling stages. Provided program integration. Also took part in the evaluation and analysis section.
- [**Kenan Selçuk**]: Examined the studies and approaches done so far. Compared the proposed approaches with the approaches in the project. Contributed to the creation of the mathematical model of the engine. Made a program suggestion.
- [**Burak Uğur**]: Researched engineering standards and tested the compliance of the current project with the related engineering standards. Also, researches were found on the limitations of the study and future approaches.

Throughout the research process, we collaborated closely, exchanging ideas, refining methodologies, and integrating our findings into a cohesive study. While responsibilities were divided, all major decisions were made collectively, ensuring the integrity and coherence of the final dissertation.

Signatures

We confirm that the contributions described above accurately represent our role in this research.

Name and Surname	**Student ID**	**Date**	**Signature**
[Kürşat Döşkaya]	[040200512]	[29.04.2025]	[+]
[Kenan Selçuk]	[040200509]	[29.04.2025]	[+]
[Burak Uğur]	[040170140]	[29.04.2025]	[+]

Constraints and Engineering Standards Used in the Report

As undergraduate students in engineering, you are constantly learning how to design, analyze, and build systems that solve real-world problems. But have you ever wondered what makes a design truly successful? It's not just about creativity or technical skills—it's also about adhering to multiple design constraints and engineering standards. These two concepts are the backbone of any accredited engineering program and are critical to your development as a professional engineer.

In accordance with the accreditation rules for the program, each and every major design project must incorporate appropriate engineering standards and multiple constraints. Therefore you must give specific importance to this section. You must clearly state what kind of constraints (**must be more than one**) are considered in your project and which boundary conditions are used to test the validity of your design. You must also provide a detailed list of engineering standards used and explain their relevance to your work. **You must ald discuss how these constraints and standards have impacted your engineering design. If you do not comply with these requirements, your project will be considered invalid, and you may need to retake the course**.

Constraints Used in the Report

The following text is only an example to emphasize significant points. Note: Don't forget to change the text.
Write this section very carefully, referring very clearly to the design section in the introduction and/or the different sections required, according to your design criteria.

Design criteria are the specific requirements that a project must meet to be considered successful. These criteria often include factors like functionality, cost, safety, sustainability, and aesthetics. However, relying on just one criterion is not enough. Engineering projects are complex, and they must balance competing priorities. For example:

A control system for an industrial robot must be precise (performance) but also energy-efficient (economics) and robust against disturbances (reliability).

An autonomous vehicle control system must be accurate (safety) but also computationally efficient (real-time performance) and adaptable to different environments (flexibility).

Using multiple design criteria ensures that your project is well-rounded and meets the needs of all stakeholders, including clients, users, and regulatory bodies. It also prepares you to think critically and make informed trade-offs, which is a key skill in engineering.

Discuss how the constraints you mention impacted your engineering design.

Engineering Standards Used in the Report

Write down the engineering standards that are actually relevant to your work and clearly state where, how, why, for what purpose, etc. they are used, by referencing the relevant sections in your thesis.

Engineering standards are established guidelines, codes, and best practices that ensure consistency, safety, and quality in engineering work. These standards are developed by professional organizations (like IEEE, ASME, or ISO) and are often legally required. For example:

Functional safety standards (such as IEC 61508) ensure that industrial automation systems operate safely and minimize risks.

Communication protocols (such as IEC 61158 for industrial networks) ensure interoperability between automation devices.

Electromagnetic compatibility (EMC) standards prevent control systems from interfering with other electronic devices.

By following engineering standards, you ensure that your designs are not only innovative but also safe, reliable, and compliant with legal requirements. This is especially important for accreditation, as programs must demonstrate that their graduates can apply these standards in real-world scenarios.

Discuss how the standards you mention impacted your engineering design.

STANDARDS AND CONSTRAINTS FORM

1. What is the design aspect of your project? Explain.

Is it a new project or repetition of an existing project? Is it a part of another project?

2. Briefly explain what the engineering problem that you have solved in your project and what is your solution on this problem.

3. Which knowledge you have learnt and which experiences you have gained throughout your university education, have you used when preparing your project?

Which lectures were useful for your project?

4. Which modern tools/software/programming languages and packages etc. did you use? Briefly explain for what purpose you used them.

5. Do you have any certificate on any other disciplines/topics in addition to the department curriculum? (For example, using online platforms such as CUDA, Udemy, Coursera)

6. Which engineering standards have you used and taken into account? How did they impacted your design?

List the standards about your project topic that must be taken into account and you have used with their names and codes. Explain how they impacted your design.

7. Which realistic limitations have you used or taken into account? Explain how they have impacted your design considering the following.

a) Economy: ....

b) Environmental Issues: ....

c) Sustainability: ....

d) Producibility: ....

e) Ethical Issues: ....

f) Health: ....

g) Safety: ....

h) Social Issues: ....

Project Team(Project Executive/Team Leader): Name Surname

Project Topic: Name Surname

Project Advisor: Title Name Surname

This project is approved by Title Name Surname (Signature)

Note: This page can be expanded for the desired constraints if it is necessary.

A

TIA Portal Program

In Chapter4, it was stated that a program was written in the TIA Portal software on PLCSim in order for the simulation environment created in the Factory IO environment to work correctly. Here, the program written in the TIA Portal will be examined. As seen in Figures A1 and A2 below, the program consists of a total of 7 function blocks. Function blocks were preferred because the program does not look too complicated and is easier to examine and write.

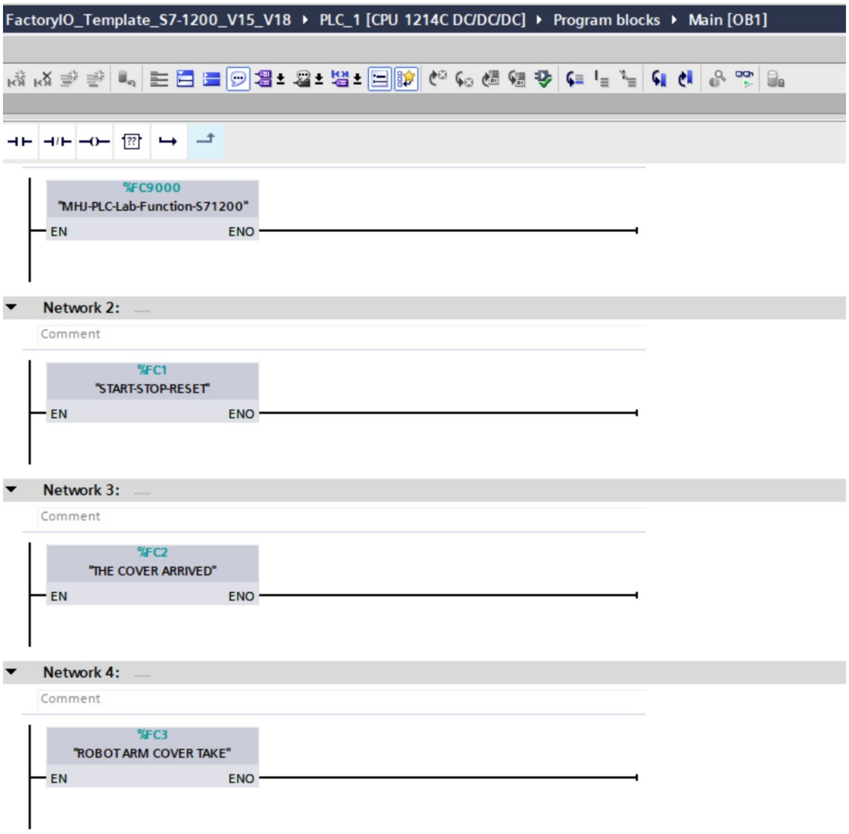


Figure A.1: First four lines of the program

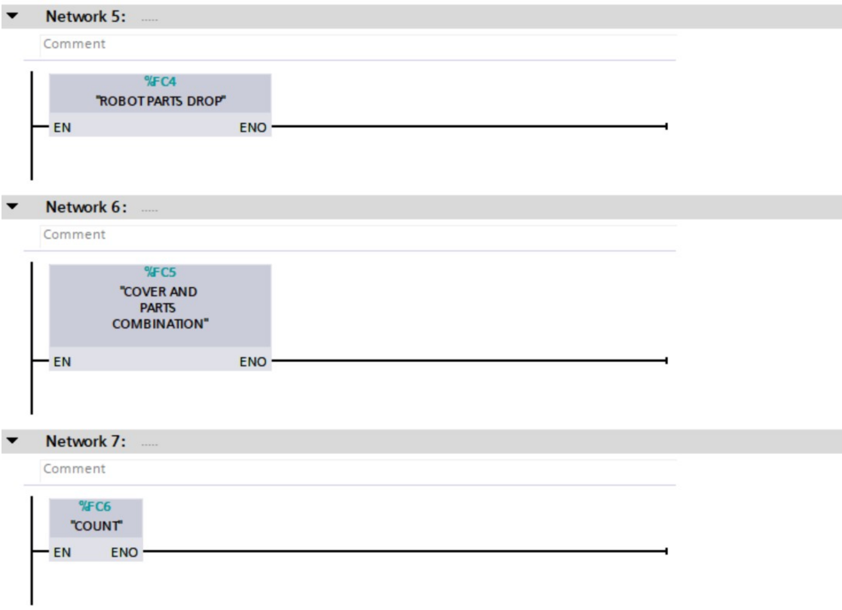


Figure A.2: Last 3 lines of the program

Here, the first function block contains a ready-made function to establish the connection between TIA Portal and Factory IO. The internal structure of the block can be seen below.

```
#Value:=PEEK(area := 16#82,
     dbNumber := 0,
     byteOffset := 511);
#Value := #Value + 1;

POKE(area := 16#82,
     dbNumber := 0,
     byteOffset := 511,
     value := #Value);

POKE(area:=16#81,
     dbNumber:=0,
     byteOffset:=1016,
     value:=#Value_01_DW);
POKE(area := 16#81,
     dbNumber := 0,
     byteOffset := 1020,
     value := #Value_02_DW);

POKE(area := 16#81,
     dbNumber := 0,
     byteOffset := 511,
     value := B#16#00);

FOR #forVal := 0 TO 120 DO
    FOR #forVal_2:=0 TO 10 DO
        #rdTimeReturn:=RD_SYS_T(#outputTime);
        #rdTimeReturn := WR_SYS_T(#outputTime);
        #rdTimeReturn := RD_SYS_T(#outputTime);
        #rdTimeReturn := WR_SYS_T(#outputTime);
    END_FOR;
    #SyncVal:= PEEK(area := 16#81,
                   dbNumber := 0,
                   byteOffset := 511);
    IF #SyncVal = #CompVal THEN
       GOTO M_1;
    END_IF;
END_FOR;
RETURN;

M_1:
POKE(area := 16#81,
     dbNumber := 0,
     byteOffset := 511,
     value := B#16#0);
Found minimum x* = 2.640388203202
f(x*) = -0.619684349427
Iterations = 5
```

Figure A.3: Function block 0

A

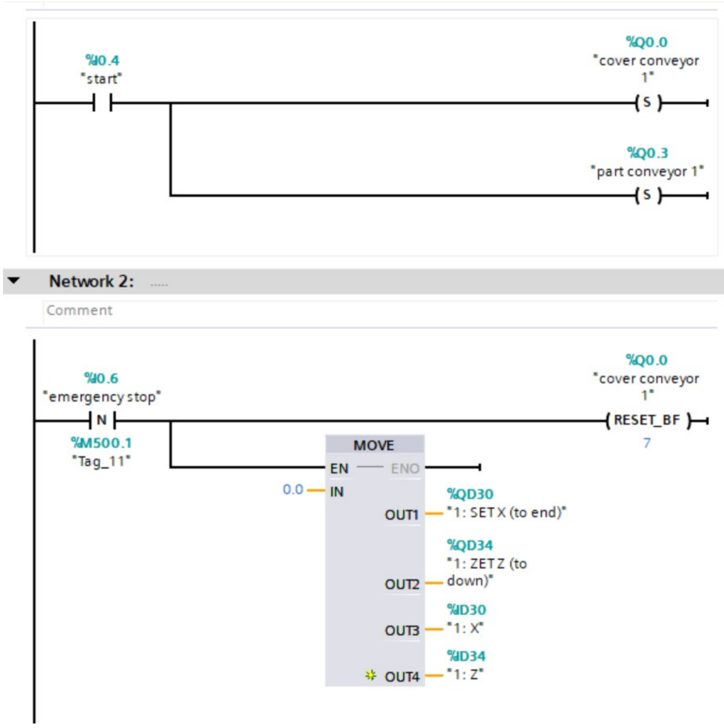


Figure A.4: Function block 1

The function block seen in Figure A.4 above aims to start the system. Since the emergency stop button is normally connected to a closed contact in Factory IO, an open contact is connected here. Then, when the start button is pressed, the system starts.

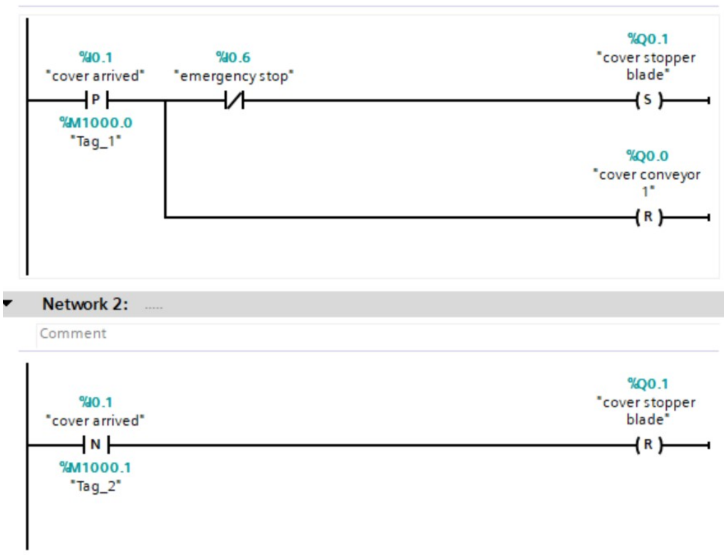


Figure A.5: Function block 2

As seen in Figure A.5 above, when the sensor detecting the cover conveyor is active, the blade on the relevant side closes and the conveyor it comes to stops. When the sensor stops detecting, the blade opens again.

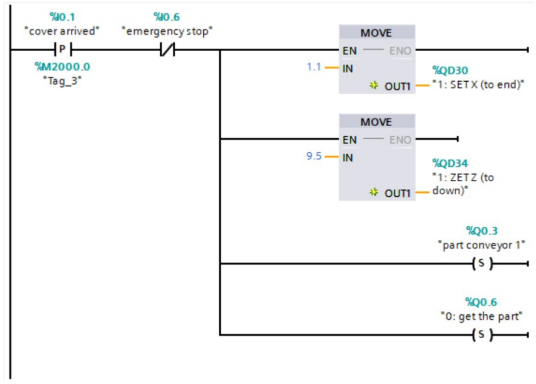


Figure A.6: Function blok 3 Network1

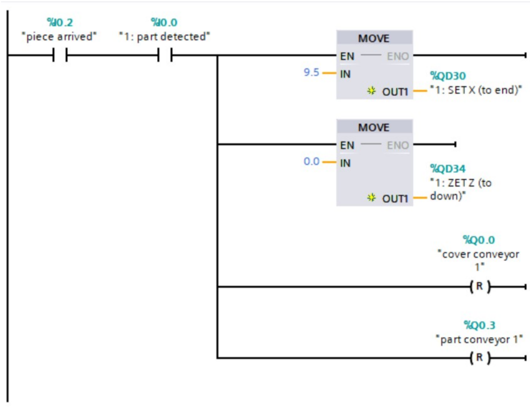


Figure A.7: Function blok 3 Network2

In Figure A.6 above, after the lid is detected, the robot arm is provided with the help of a gripper to take the lid. These values are provided to the x and z coordinates that were previously set by trial, that is, to be approximately on top of the lid. In Figure A.7, the lid is taken to the determined coordinates and made ready to be combined with the part.

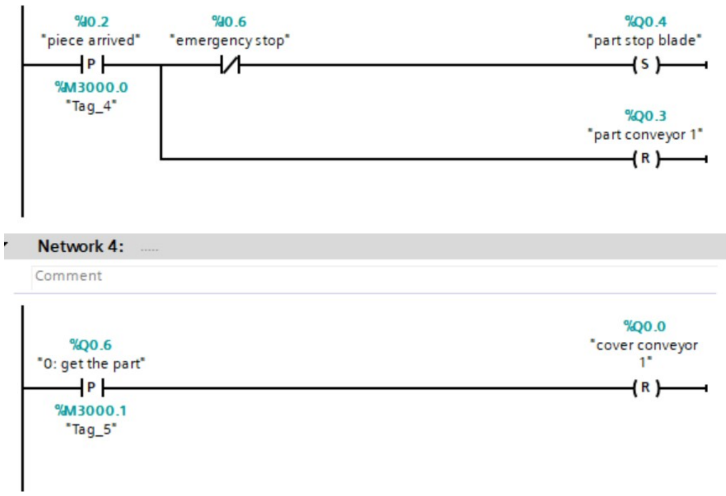


Figure A.8: Function block 3 Network3 and Network4

In Figure A.8 above, when the part sensor detects the object, the blade becomes active and the conveyor on which it stands goes into the off position. At the same time, after the gripper holds the lid, the lid conveyor stops accordingly.

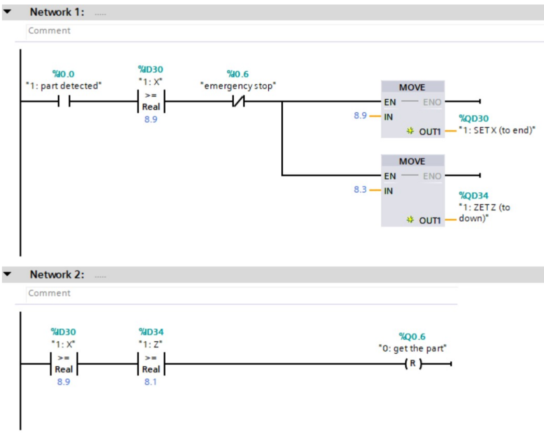


Figure A.9: Function blok 4 Network1 and Network2

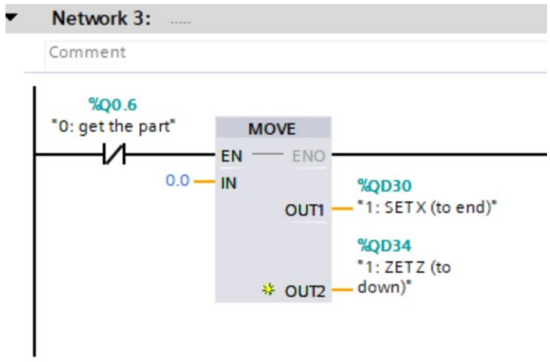


Figure A.10: Function blok 4 Network3

In Figure A.9 above, when the robot arm reaches the desired position, it is assembled by dropping the cover onto the part.

In Figure A.10, the robot arm returns to the set starting position after releasing the lid.

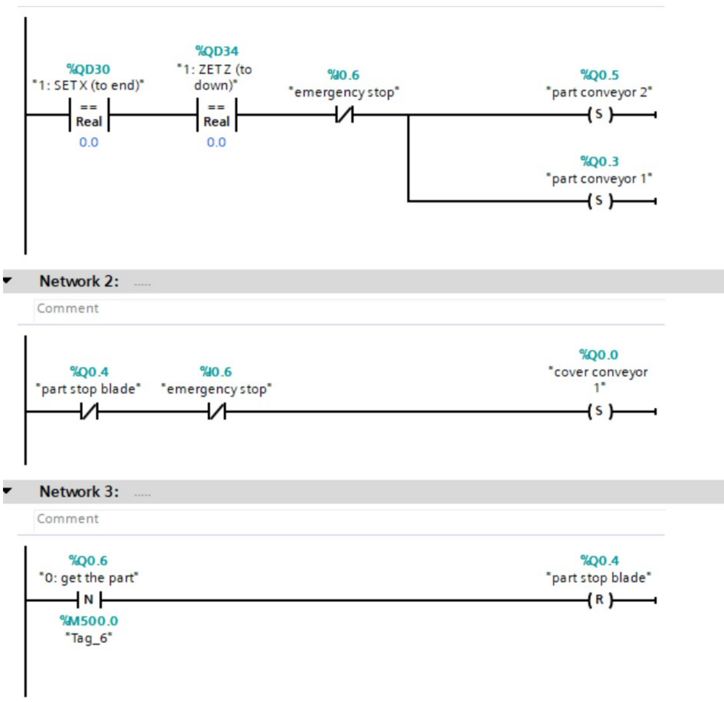


Figure A.11: Function block 5 Network1 to Network3

In Network 1 and Network 2 above, the conveyors are restarted. In Network 3, after the gripper releases the cover, the blade in front of the product is lifted. In this way, the product can move forward on the part conveyor.

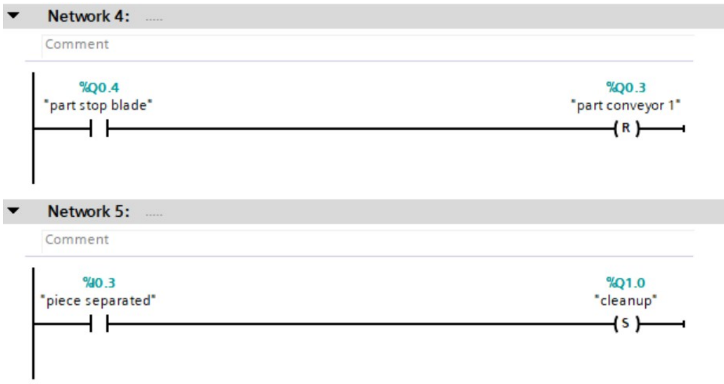


Figure A.12: Function block 5 Network4 and Network5

In Network 4 above, if the part blade is open, unnecessary operation of the 1st part conveyor is prevented. In this way, energy saving is achieved. In Network 5, after the created part passes the part separation sensor, the remover that cleans the created part at the end of the belt is activated.

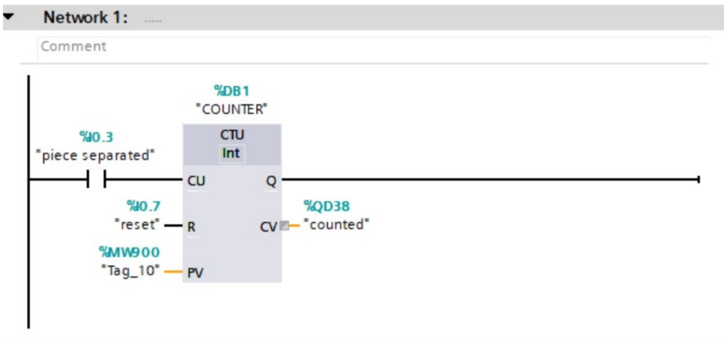


Figure A.13: Function block 6

Here, a program part is seen where the products produced in the system are counted with an up counter block after the object created passes through the part separation sensor. A reset button is assigned to reset the counting process.

A

B

DC Motor Matlab Modeling

Below you can see the modeling of a DC motor in the Simulink program and the internal structure of the DC motor.

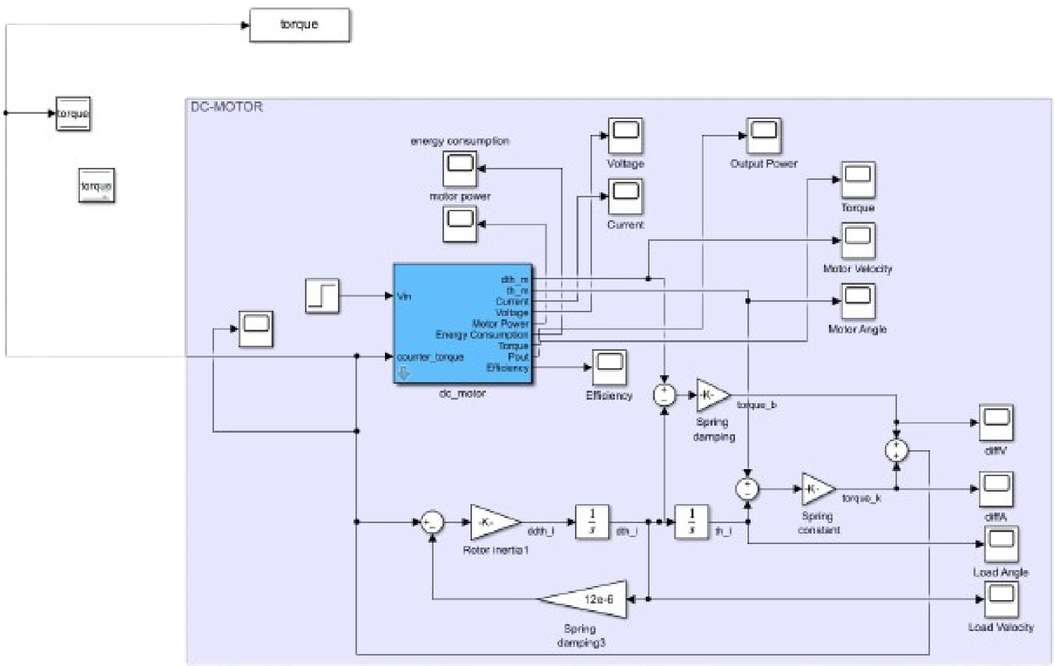


Figure B.1: Simulink model of the DC motor

A Simulink drawing of a DC model was created above. From here, the current, torque, etc. quantities were taken and the energy consumption and efficiency of the motor were measured.

The internal structure of a DC motor is shown above. Depending on these, any information desired from the current-time expression of the system to the efficiency expression can be obtained.

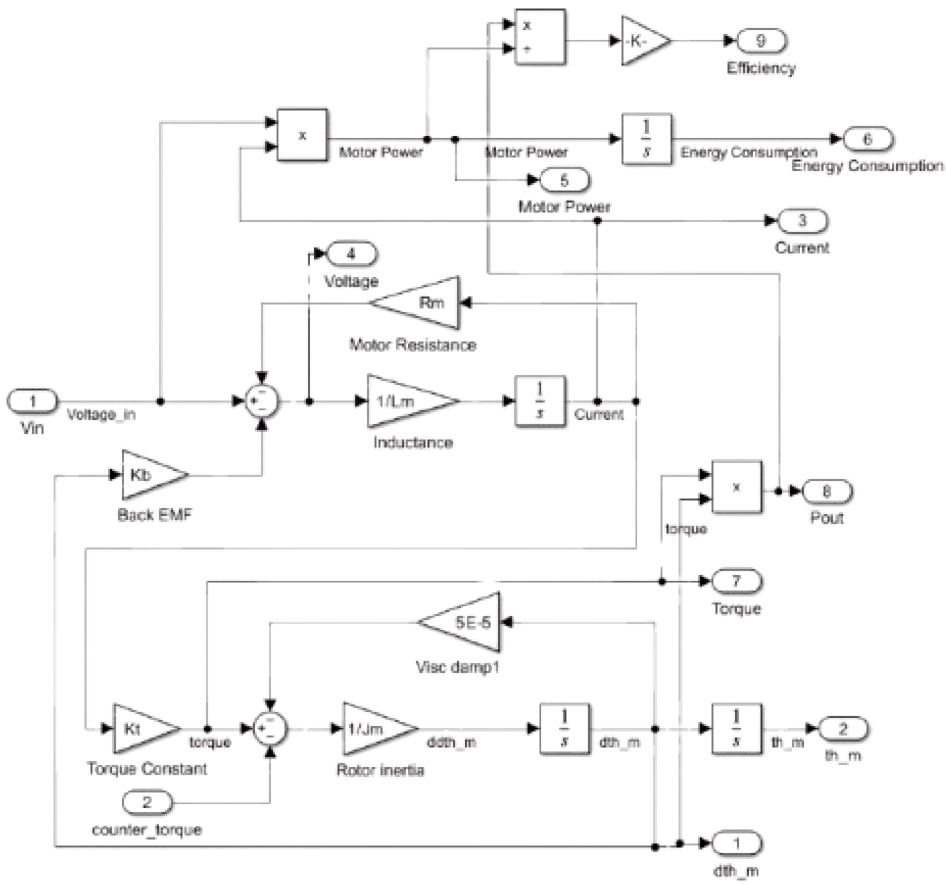


Figure B.2: Inside of the DC motor

The current is equal to the integral of the output voltage divided by the inductance value with respect to time. The current-time graph is shown below:

$$i = \int_0^t \frac{V_{\text{out}}}{L_m}\, dt \tag{B.1}$$

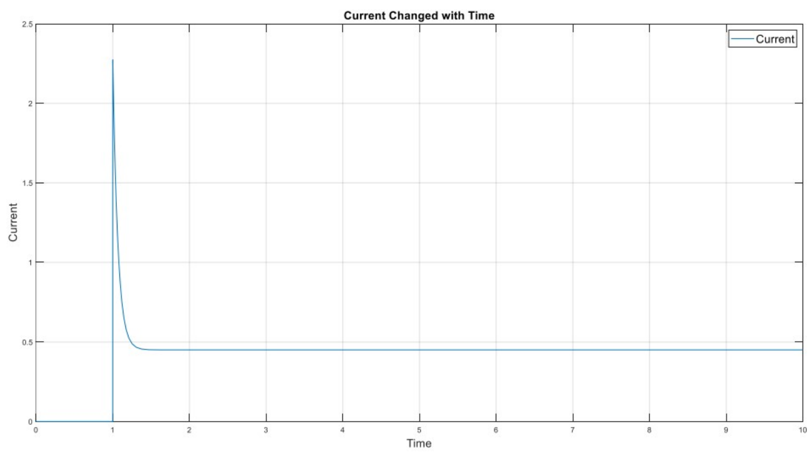


Figure B.3: Current-time graph

Torque is equal to the product of the torque constant and the current. Below is the torque time graph.

$$u = K_t i \tag{B.2}$$

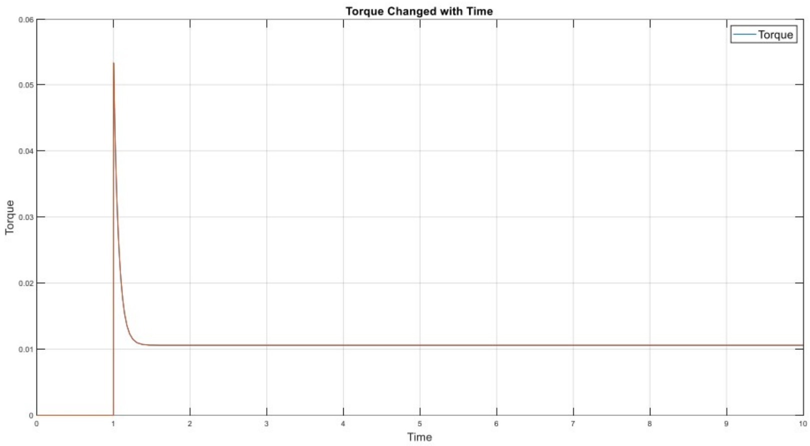


Figure B.4: Torque-time graph

B

The counter torque created by the load is as shown in the graph below. This acts as a distorting effect on the DC motor.

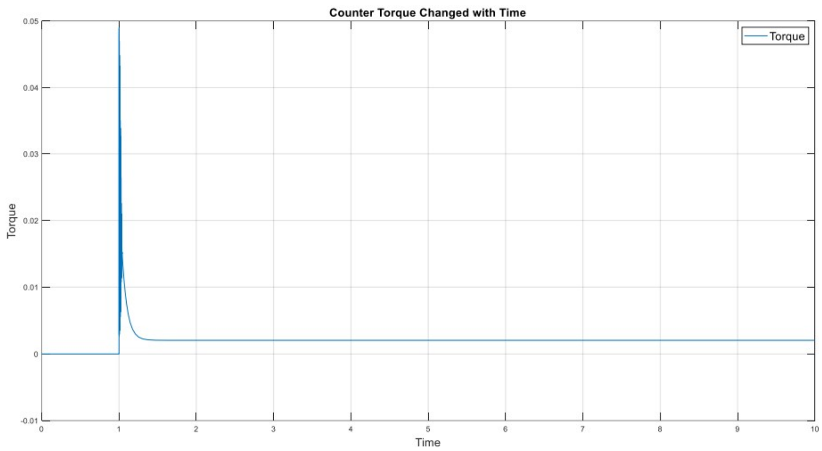


Figure B.5: Counter torque-time graph

The angular velocity of the motor is equal to the integral of the angular acceleration of the motor. Here we see that the motor increases rapidly and then settles to a constant value.

$$w = \int_0^t \alpha \, dt \tag{B.3}$$

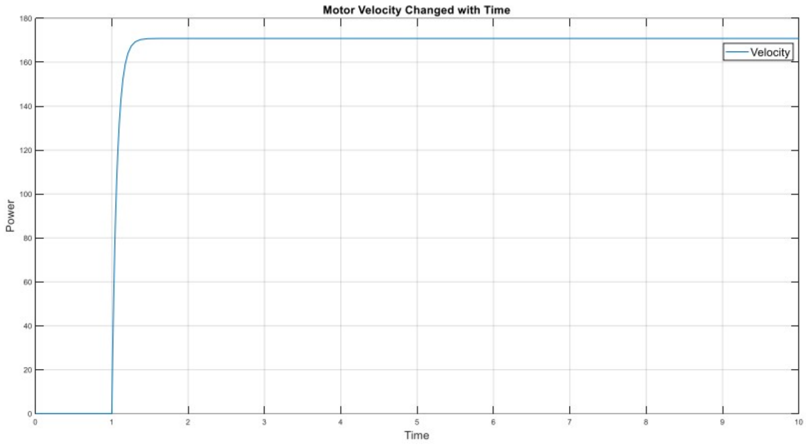


Figure B.6: Angular velocity-time graph

The angular position of the motor, that is, its angle, is equal to the integral of the angular velocity of the motor. In other words, it is the second integral of its angular acceleration. Here, it is seen that the angular increases linearly. Its unit is radian.

$$\theta = \int_0^t \int_0^t \alpha \, dt \tag{B.4}$$

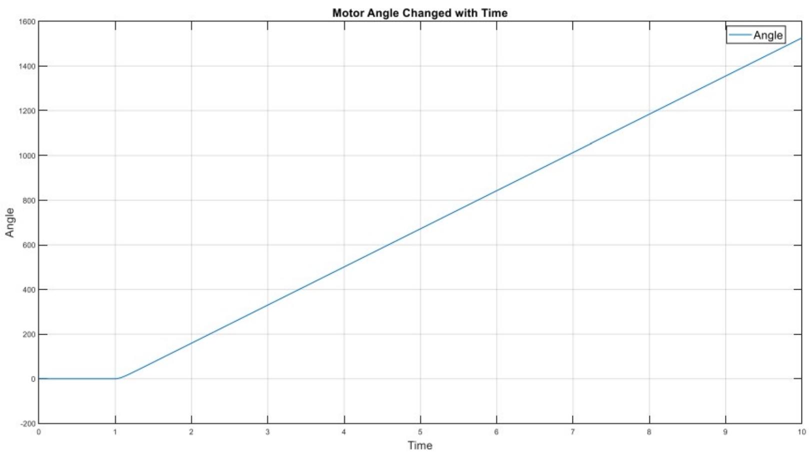


Figure B.7: Motor angle-time graph

The speed-time graph of the load is as follows

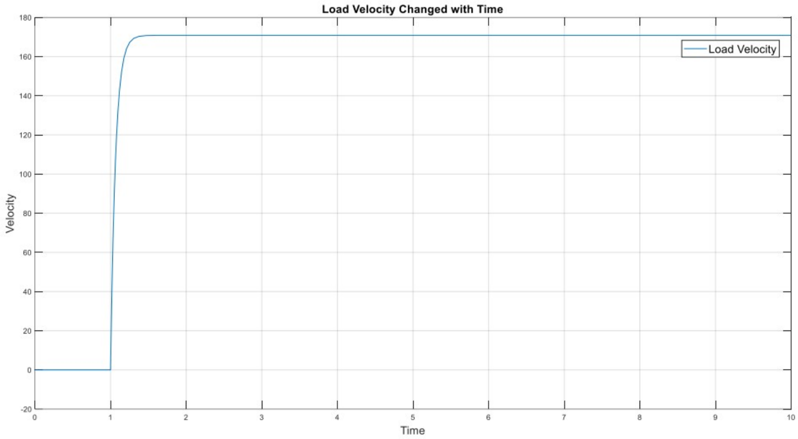


Figure B.8: load speed-time graph

The angular position-time graph of the load is as follows.

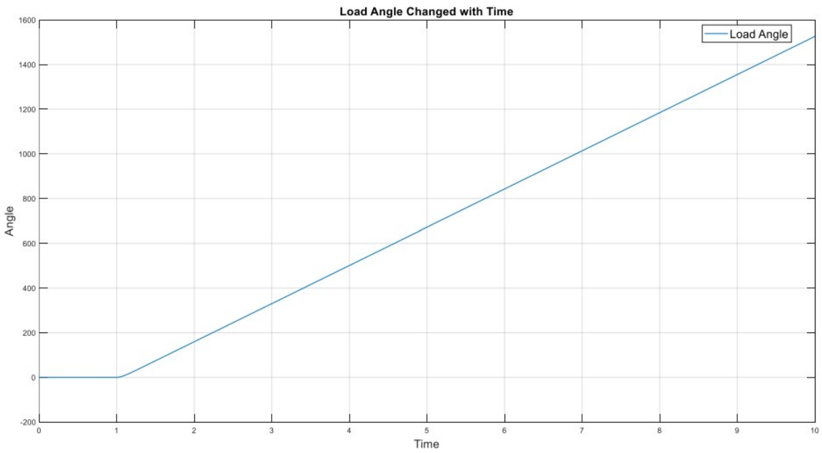


Figure B.9: load angular position-time graph

In the simulation, the voltage of the DC motor was initially given as 5 with a step. Then, with the effect of back emf, resistance and coil, this voltage was equalized to zero.

$$V = V_{in} - V_{backemf} - RI \tag{B.5}$$

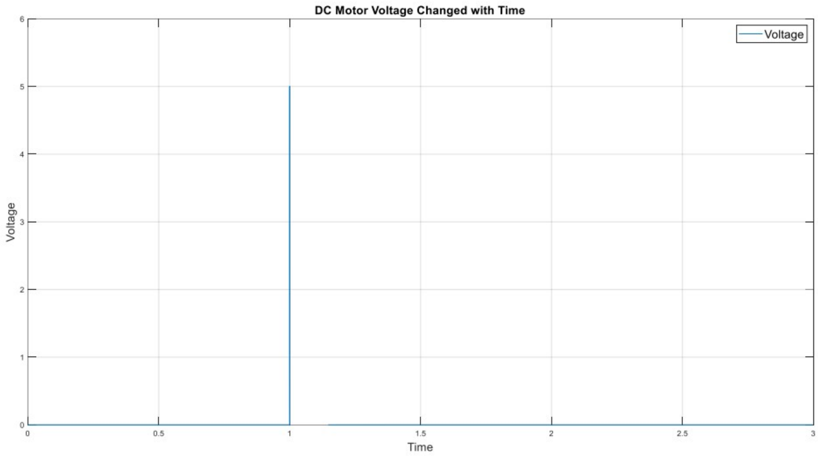


Figure B.10: DC motor voltage-time graph

Motor power is formulated as the product of input voltage and current. Motor power time graph is as follows

B

$$P_{DC} = V_{in}I \tag{B.6}$$

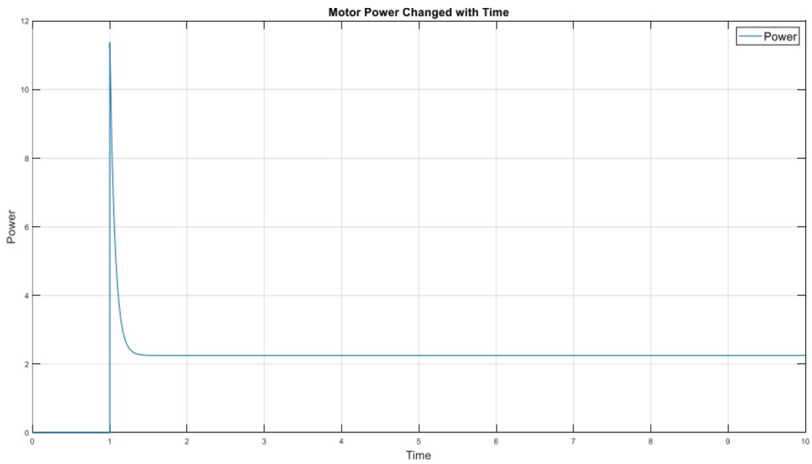


Figure B.11: Motor power-time graph

Output power is equal to the product of the system torque and the motor speed. It is an important parameter in calculating efficiency. The graph is as follows.

$$P_{out} = \tau W \tag{B.7}$$

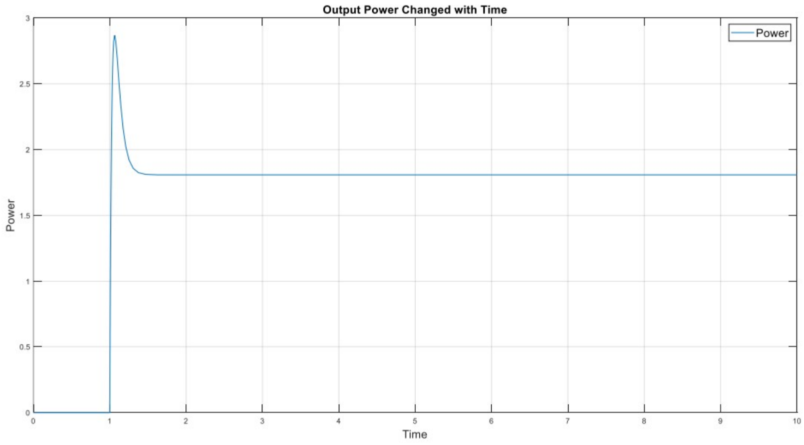


Figure B.12: Output power-time graph

In physics, the energy consumed is calculated as the integral of the power. Here, the integral of the motor power represents the energy consumption of the system

$$Consumption = \int_0^t P_{out}\, dt \tag{B.8}$$

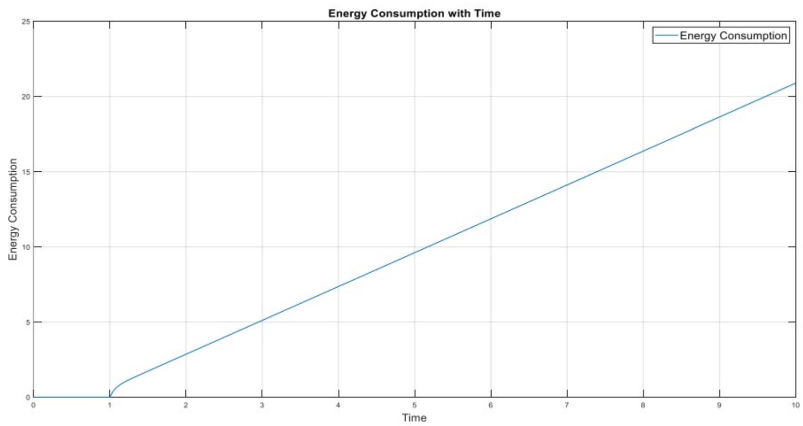


Figure B.13: Energy consumtion-time graph

Efficiency is the measure of the extent to which the power given at the input of a system can be preserved at the output. Because the integral of the power gives the speed. Here, efficiency is the ratio of the output power to the input power. A gain block was multiplied to calculate as a percentage. It was determined that our engine operated at 80parameters and this load.

$$\eta = \frac{P_{out}}{P_{DC}} 100 \tag{B.9}$$

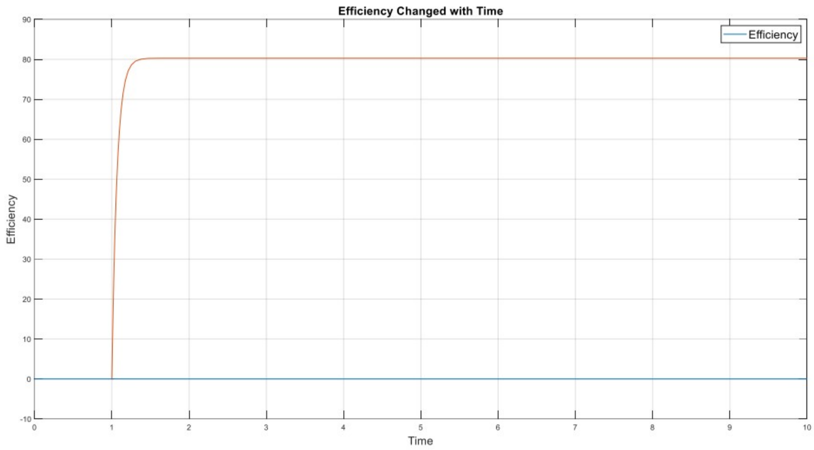
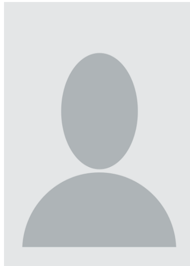


Figure B.14: Efficiency-time graph

B

Resume 1



Kürşat Döşkaya

doskaya20@itu.edu.tr |

Education

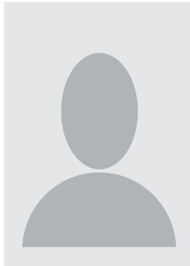
- **Istanbul Technical University** **Istanbul, Turkey**

  Control and Automatıon Engineering *2020 – 2025*

Resume 2

Kenan Selçuk

selcuk20@itu.edu.tr |

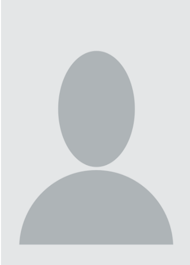


Education

- **Istanbul Technical University** **Istanbul, Turkey**

  Control and Automation Enginering *2020 – 2025*

Resume 3



Burak Uğur

ugurb17@itu.edu.tr |

Education

- **Istanbul Technical University** **Istanbul, Turkey**

  Control and Automation Enginering *2020 – 2025*