Virtual Commissioning of an industrial wood cutter machine

A software in the loop simulation

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Preface

I dedicate this thesis to my beloved wife Paulina that supported me through the whole process. Also to my children Lilith and Dorian that give happiness to my life and always remind me that love is all it takes to be happy. And last but not least, to my mother Veronica who taught me to never give up on my dreams.
Abstract

The methods used today for the commissioning and validation of industrial machines requires the construction of physical prototypes. Those prototypes help the engineers to e.g. validate if the program code meant to control a machine works as intended. In recent years the development of new techniques for the commissioning and validation of industrial machines has changed rapidly thanks to the development of new software. The method used in this thesis is called simulation in the loop. Another method that can be beneficial to use is hardware in the loop. Using those methods for the commissioning of a machine is called virtual commissioning. The simulation in the loop method is used to simulate both the machine and the control system that operate that machine. This is called a digital twin, a virtual copy of the physical hardware and its control system that can be used without the need for a real prototype to be available.

The software used in this thesis comes all from the company Siemens and those are TIA Portal, Mechatronics Concept Designer, SIMIT and PLCsim Advanced. By using those programs it was possible to build a digital twin with rigid body dynamics and its control system of the industrial model that was given by the company Renholmen AB. This model contained all the necessary components needed for a virtual commissioning project to be done without the need to be at the factory floor.

The results showed that it was possible to achieve a real time simulation, allowing the possibility to trim the controller parameters without the need of a physical prototype. Design errors were also found thanks to the results of the simulation.

This new technique has shown to be a useful tool due to most of the work could be done on a digital model of the machine. Simulations can reduce the time to market for industrial machines and also help engineers to validate and optimize the product at an early stage. This tool that can be used to validate industrial machines before they are created.

**Keyword:** Virtual commissioning, PLCSIM advanced, digital twin, mechatronics concept designer, SIMIT, TIA Portal, PLC, HMI, software in the loop.
### Abbreviations

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<td>ADAS</td>
<td>Advanced driver assistance systems:</td>
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<td>CAD</td>
<td>Computer aided design</td>
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<td>FBD</td>
<td>Function block diagram</td>
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<td>HIL</td>
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<td>Human machine interface</td>
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Glossary

**Digital twin**: Virtual model of a physical product, service or process.

**Function block diagram**: A standard programming language used with the purpose of controlling mechanical devices often in industrial applications.

**Hardware in the loop**: Method used in many engineering domains to simulate the behavior of hardware partially. The process or machine is simulated while the physical control system is connected to the simulation.

**Human machine interface**: User interface for a certain control system, machine or device.

**Industry 4.0**: Unifying term for a range of technologies and concepts in automation.

**Ladder diagram**: A standard programming language used with the purpose of controlling mechanical devices often in industrial applications.

**Mechatronics concept designer**: Software from Siemens used to recreate electromechanical behavior of an CAD object.

**PLCSIM Advanced**: Software used to simulate PLC controllers from Siemens.

**Programmable logic controller**: Piece of hardware used to control mechanical devices often in industrial applications.

**Renholmen industrial machine**: Machine designed by the company Renholmen with the purpose of adjusting wood planks more efficiently.

**SIMIT**: Software developed by Siemens that can be used as a communication bridge between other Siemens products such as TIA Portal and MCD.

**Software in the loop**: A method used in many engineering domains to simulate the behavior of hardware with embedded software such as complex manufacturing machines.

**Totally Integrated Automation Portal**: Software developed by Siemens that provides tools for automation solutions.

**Virtual commissioning**: Method used to create a digital twin of a machine with the objective of reducing the commissioning time if possible.
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1 Introduction

This project started in November 2018 at Luleå University of Technology in cooperation with Renholmen AB and by the support of Ditwin AB. The idea to create a digital twin of a machine and test its capabilities led to the concepts of virtual commissioning (VC), a concept that is gaining significant attention in this new era of digitalization. One important concept in VC is software in the loop (SIL) which allows machine builders to deliver high quality products in less time. The use of VC makes it possible to simulate, optimize and validate machines before they are manufactured.

1.1 Company background: Renholmen AB

Renholmen AB was founded in the village of Renholmen in 1952. The main focus at that time was hydraulic gear pumps and repairs of those. In 1972, Renholmen decided to move to the newly built factory premises in Byske where they started the manufacturing and delivery of sawmill equipment (1).

In 2003 the production and manufacturing side of the company moves to FeRex AB and in 2004 they changed the name to Renholmen AB. Under the following years Renholmen AB became a company specialized in sawmill equipment and timber management for all kinds of processing in the wood industry (1).

Renholmen AB has great engineering knowledge in the making of premium machines, lines, and equipment that handle wood. Renholmen AB is open to new and innovative methods that can improve their way of working (2).

1.2 Company presentation: Siemens

Siemens is a company who produces equipment and software in many different sectors such as industry, energy, and healthcare just to name a few. Their roots initiate in Germany and have spread all over Europe and the whole world (3).

Siemens was founded in 1847 and has developed many new groundbreaking products, solutions, and services. One of Siemens first products was telegraphy and telex innovation, and from there it took off to new and more exciting products. Siemens is a company that develops products in different areas such as digital innovation, power distribution, conventional power plants, and industrial communication. In 1958 a new and groundbreaking product was introduced to the market which would be the core of all automation solutions by Siemens. This product was called SIMATIC and contains software and hardware solutions for all kinds of automation tasks such as controllers, IO systems and HMI just to name a few (3),(4).

Siemens launched a new software architecture to the market for automation devices in 2010: Totally Integrated Automation Portal (TIA Portal). TIA Portal became the foundation of all future engineering systems for the planning, programming, and commissioning of automation devices and drive systems in the Siemens Totally Integrated Automation (TIA) range. TIA Portal became the heart for all the engineering functions in a single framework with a uniform user interface (5).
1.3 Purpose
The purpose of this thesis was to implement a proof of concept in VC by using the SIL method with the help of Siemens software. This work also covers techniques used to test and analyze the behavior of a model in a virtual environment without the need for a physical product.

1.4 Problem description
To validate if a machine works as intended the commissioning process is required. This process takes time due to the need for a physical prototype. This time can be reduced by using a digital twin which is a digital copy of the physical machine and its control system. This testing method is called virtual commissioning and can be used to speed up the development of new machines.

1.5 Research questions
The concepts of VC are new and therefore is important to investigate how it can be used to improve the way machines are tested. The questions this thesis cover are the followings:

- How does VC speed up the time to market of a product compared with the methods used in today’s industries?
- Which are the essential steps needed to start a VC project?
- What benefit can it give to the different engineering departments?

1.6 Resources
The resources given for this work consisted of a workshop in SIMIT, TIA Portal and MCD at Siemens Solna Stockholm. Ditwin AB provided a computer capable to run the simulations smoothly. The help of my supervisor Peter Jeppsson was appreciated during the project and he was available daily. The licenses that were granted by the university were the following: TIA Portal, SIMIT, NX/MCD, and PLCSIM Advanced.

1.7 Limitations
This work covers the SIL method using software from Siemens. The project does not include the creation of the CAD model because the model was already constructed by Renholmen AB. The testing of the real PLC code meant to control the machine was not tested.

1.8 Project packages
This work was divided into seven work packages:

- Construction of the dynamics of the industrial machine in MCD
• Simulation of the motor drives in SIMIT
• Connectivity between NX/MCD, TIA Portal and SIMIT
• Demo program for motion control in TIA Portal
• Human Machine Interface demo
• Setup of the technology objects in TIA Portal
• Device configuration in TIA Portal
2 Theoretical background

The theoretical background presented in this section covers a variety of concepts that are the building stones of this thesis.

2.1 Industry 4.0

In the history of industrialization, there have been three major industrial revolutions. The first was the steam and water power. The second electricity and assembly lines, and the third was computerization, and now we are on the brink of a new revolution, Industry 4.0 (6).

The industry 4.0 stretches over many areas combining three essential groups which are: the cyber physical system, internet of systems, and the internet of things (6). The idea is to build smart factories that contain those three groups. The factories will be equipped with advanced technology such as robots, artificial intelligence, sophisticated sensors, and cloud computing. With all this equipment the factories will be able to visualize the entire production chain, and they will be able to learn from others and adapt (7).

Industry 4.0 enables new ways of working. The existing and upcoming industries need to adapt to get the benefits from it (8). A few new possible applications are the following:

- Identify opportunities: Connected machines can store a large amount of valuable data. That stored data can lead to information that regards maintenance, performance, and other issues. The data can as well be used to analyze and identify patterns, insights that otherwise would be missed or not been possible to make in a reasonable time frame.

- Autonomous equipment and vehicles: Autonomous equipment is added to the industry making the work faster and more accurate.

- Optimize logistics and supply chains: When a supply chain is connected, it can adjust and accommodate new information when it is presented.

- Robots: Industrial equipment is more affordable and even smaller organizations have the opportunity to own autonomous robots that quickly and safely can support manufacturers.

2.2 Virtual Commissioning

The development of new machines requires the knowledge of different areas of engineering since mechanical and electrical machine elements as well as programming are a requirement to run a machine.

The methods used today for the development of new products are often sequential which means it has to be performed in a specific order. Mechanical, electrical and automation are completed separately one after the other to construct and test a new product (9). Engineers need to wait for each stage to be completed before getting involved in the project. The only way for the engineer to validate the program code is e.g. to test it on a prototype and if errors are found in the later stages of the process, time and cost increases. This way of work can be improved by the use of VC making the process faster and less expensive.
The life cycle of product development can be represented in different stages depending on the model used. One model is the six sigma model which is a way to represent a process improvement. The model shows that the cost increases by a factor of ten per development step \(^{10}\), as it can be seen in Figure 1.

![Cost per error vs. Product life cycle](image)

Figure 1: The product cost increases by a factor of ten per phase as it is shown in this graph.

It is here where VC comes in play. VC is a method used to create a digital twin of a machine. This digital twin is a virtual copy of the real machine and its purpose is to capture all the behaviors of it to make tests and simulations, often in a 3D environment. By doing this type of simulations, the production time can be reduced remarkably which means time saving and higher profit. The possibility to test the program code without the need of a real prototype leads to a reduction of commissioning time that is estimated up to 75% \(^{11}\).

Some methods used for VC projects require CAD files that need to be created and imported to simulation software. There are many types of simulation software for VC, some offer the possibilities to develop simple CAD models and have libraries with parts often used in industries as conveyors and other types of machinery. In those software, kinematics can be added to the models as well as sensors and signals. The signals inserted in the model are later connected to the control system of the machine known as a programmable logic controller (PLC). The validation of the PLC program can then be tested at an early stage. This leads to the possibility to elaborate a more reliable code but also make the process of the real commissioning shorter.

The commissioning of a product can be made in four different ways as shown in Figure 2. The two most important VC setups are hardware in the loop (HIL) and software in the loop (SIL). They are both similar in the way that both used a virtual object as a model, however, in HIL a piece of real hardware is connected to the simulation \(^{12}\). The SIL method is the one used in this thesis and is explained in more detailed in section 2.3.
There are several suppliers of VC simulation platforms, e.g., Emulate3D, Xcelgo, Visual Components, and MCD by Siemens just to name a few. A short description of those software are described in the master thesis Virtual Production Line by Joel Persson and Jesper Norrman (13).

2.3 Software in the loop

The software in the loop (SIL) is a method used in many engineering domains to simulate the behavior of hardware with embedded software such as complex manufacturing machines. An example of how SIL can be implemented is how Mladenvic M and Abbas M did in their project that was about traffic control; it was compounded by a virtual traffic controller, microscopic simulation model, and interface to communicate between the two components (14). The SIL method can be used to simulate a complex system through a direct and iterative test, and it is possible to modify the source code. The SIL simulation has many benefits, one is to run the program code at an early stage without the need for a prototype. Another advantage that goes along with the software test, is the acceleration of the development cycle. SIL is capable of detecting early system-level defects or bugs, and that will benefit in later stages the production (15).

2.4 Hardware in the loop

Industrial machines used today have very complex systems built into them. To be able to test those systems is necessary to have methods that have the potential to handle it. One method to test those
systems is to make use of a hardware in the loop (HIL) simulation. In the vehicle industry, the level of complexity is moving faster than ever and to remain relevant in today’s market there is no room for error. Modern vehicles have Advanced Driver Assistance Systems (ADAS), radar, cameras, and more. A HIL simulation can be very useful to reduce the load in the final assembly test. HIL allows the engineering team to test the systems at an early stage freely, and the simulations can be done often to uncover as many software defects as possible. In a HIL test, a specific technique is used: real signals from a physical controller are connected to a virtual model of a machine that will simulate the reality. It tricks the controller into thinking it is in controlling a physical machine.

2.5 Digital Twin

Digital Twin is a concept that has been around since 2002 but not used by industries due to the cost and its implementation (17). However, the Internet of Things (IoT) evolved and made possible for industries to combine digital twins with IoT technology to their manufacturing methods. All thanks to the ability to transfer data by the use of the internet. A digital twin is a virtual model of a physical product, service or process. The benefit with a digital twin is the possibility to test a concept in a virtual environment. The simulation gives data to analysis, and the data will provide the information to see the problems before they occur. This will minimize downtime, and gives the possibility to develop harder projects and even plan for the future. The digital twin has grown in a short time and nowadays it is possible to include larger items such as the human body, buildings, factories, and even cities. An excellent example of what a digital twin is can be described as following: "imagine it as your most talented product technicians with the most advanced monitoring, analytical, and predictive capabilities at their fingertips" (17), (18).

2.6 PLC

A programmable logic controller (PLC) is a piece of hardware used to control mechanical devices often in industrial applications, e.g., valves and pumps. Its robustness against harsh environments makes the PLC a reliable controller for industrial automation. The capability for modularity makes it also easy to adapt to a different application, just by adding more modules the numbers of digital and analog inputs and outputs can be chosen as desired.

At the beginning PLCs were made by logical component switching relays to control operations. However, evolution in technology has made it possible to create more advanced PLCs capable of more complex operations (19). The PLCs has a variety of different languages for programming which are defined by the international standard IEC 61131-3. This standard is composed by three graphical and two textual programming languages (20).

- Ladder diagram (LAD) - Graphical language
- Functional Block (FBD) - Graphical language
- Sequential Function Chart (SFC) - Graphical language
- Instruction List (IL) - Textual language
- Structured Text (ST) - Textual language
The PLC programmer has also the ability to display the code of the program using graphics displayed in a panel. Those graphics could be buttons or graphs that tell the operator or floor supervisor information about the system. This type of visual representation of the code is called HMI and stands for the human machine interface.

2.7 Industrial communication

To be able to send data back and forward between sensors and actuators in the industry floor a specific communication protocol is needed. They are several communication protocols such as Profinet, Profibus and CAN buss just to name a few; all those have different communications properties. In the early days, some communications limitations were caused by many different factors, e.g. the parallel cabling between sensors, actuators, and controllers. To solve this problem, a new system was developed; a dedicated automation network called Fieldbus (21). Fieldbus did also close the communication gap in the lower levels of the automation pyramid as shown in Figure 3.

![Figure 3: The pyramid shows the architecture of an industrial floor. The Fieldbus is represented by the lines connecting the devices in every floor.](image)

The millennium rolled in and the industrial communication changed drastically by the introduction of a new connection based on an Ethernet network, a technology from the IT world (22). Industrial communication is a way to have overall control and communicate with everything in an industrial setting. Industrial communication has become such a vital part of the industry that without it, many complex tasks would be impossible to control efficiently and productively. Some of those tasks are managing power distribution, control of machines, entire production lines and monitoring transportation systems (23).
3 Virtual Commissioning toolbox by Siemens

Siemens as a company offers a large variety of simulations software for VC. Depending on the level of complexity and the scale of the commissioning, different software are available and can be used or combined to get more accurate results. A description of the software used in this thesis are summarized below.

3.1 NX

The computer aided design (CAD) software NX from Siemens has a large variety of tools for the design of products, e.g. drafting, routed systems, PID design, FEM analysis, and manufacturing just to name a few. Another option that makes this software a great tool for engineers is the add-on Mechatronics Concept Designer.

3.2 Mechatronics Concept Designer

Mechatronics Concept Designer (MCD) is a product that allows different disciplines as mechanical, electrical and automation engineers to work together. This approach provides an end-to-end solution that gives the benefit of reducing product development time. The software uses a physics engine similar to the ones used in video games to simulate physical behavior as it was the real world. This enables the possibility to test how systems may react when forces are applied and identify if there are collisions between objects that may affect the system. There is also possible to test the control system of a machine in real time when is connected to SIMIT.

A CAD model is required to validate a particular product in MCD. MCD can directly open CAD models in the NX CAD format, either from files on disc or from the PLM software "Teamcenter" which is a system for managing product data during the entire product life cycle. CAD models from other software can also be used in MCD.

To add physical behavior such as gravity, some parameters must be added to the model first. Those parameters are defined as rigid bodies, collision bodies, and joints. The software also offers the capability of adding sensors, actuators, and signals to control the model. The signals can be trigger directly from the software but also externally. This gives the possibility to run the model from a virtual or real PLC.

A summary of the advantages that mechatronics concept designer gives to the different disciplines involved in the development of machines are described below:

- **Mechanical**: Engineers involved in the mechanical design of a product can use all the tools that NX brings to create high quality modeling. The software can also read different file types from other software such as STEP, AUTOCAD, and CATIA, just to name a few. This makes MCD a very useful tool for the validation of concepts.

- **Electrical**: This area of engineering is responsible for the electrical components to work as intended. MCD offers the possibility to add signals and actuator to the simulation and also import files in Excel spreadsheet format.
• **Automation**: Engineers in this field often come last in the chain of machine development. By using MCD the dynamics of the machine can be captured using a digital twin. Then it is possible to validate the PLC program at an early stage, allowing to create more sophisticated and elaborate programs.

### 3.3 PLCSIM Advanced

PLCSIM Advanced is used to simulate the PLC controller S7-1500 among others. This makes it possible to test the logic of a program without the need for the physical controller. This is an essential part of the SIL approach, as the main idea is to simulate the physical control system. The ability to simulate the PLC S7-1500 family and connect it with third party software as MCD and SIMIT makes this software an important tool in VC simulations (27).

The advantages of PLCSIM Advanced for the SIL method used in this thesis can be summarized as follow ”The ability to upload and run code without the need of a physical PLC”. This avoids costs for hardware in the simulation environment. It also reduces the risk of the commissioning as the risk of damaging equipment is minimized.

### 3.4 TIA Portal

Totally integrated automation portal is a software developed by Siemens that provides the engineer with a large range of digitized tools for automation solutions. The benefits of using TIA Portal can lead to increased productivity, time saving, and enables the capability for testing the machinery (28). TIA Portal can be used in many different applications e.g. to simulate and test a product before implementation in the real world (29).

A sum of the most important TIA Portal packaged used in this thesis are described below:

- **PLC programming with SIMATIC STEP 7**: Program package used to write PLC code. This package contains five different programming languages. Those are control system programming standard used in the automation world.

- **Visualization with SIMATIC WinCC**: This packages added in TIA Portal allows the user to create control screens in which the program code can be visualized and displayed in form av e.g. graphs and animations.

- **Motion Control**: This package allows the possibility to define the operating parameters of actuators such as motors and valves to make them operate as desired. Some of the parameters that can be adjusted are e.g. motor load and operation mode (linear or rotational), max speed, acceleration, and deceleration just to name a few.

### 3.5 SIMIT

SIMIT is a software used for virtual commissioning that allows real time simulation (30). SIMIT allows the possibility to import signal from other software as MCD and TIA Portal and connect them, making it possible to simulate electromechanical systems among others and get visual results. The role of SIMIT in this thesis was to import the control signals from both TIA Portal and NX and to connect them. By doing this connection the speed of data transfer between programs could
be selected up to some milliseconds enabling real time simulations.

The advantages obtained in this SIL project are summarized below:

- **Faster commissioning**: SIMIT allows the commissioning process directly from the office. This can lead to better products due to the ability to identify errors at the early stages. The time that can be reduced using SIMIT can often be up to seventy percent.

- **Higher engineering quality**: The use of SIMIT makes it possible to extend the testing time in projects which lead to higher quality results. Various faults can be simulated in SIMIT to avoid costly re-engineering.

- **Lower costs**: The cost can be reduced thanks to the ability to detect errors early in projects. Also using SIMIT the time used to assembly, connect and test automation programs with real hardware can be reduced.

- **Reduced risks**: SIMIT enables the possibility to test safety functionalities and different operation errors without the need for physical equipment or factory employees. This avoids expensive damage that can occur when testing with the real equipment.
4 Simulation in the loop

This section explains how the creation of the digital twin was made in MCD. Also, detailed explanations of the most important steps taken in MCD, SIMIT and TIA Portal are explained to give the reader a good understanding of why and how those software were used in the SIL. All steps needed to create the connections between the software named above are also explained.

4.1 Creating a mechatronic model in MCD

The first step taken was to load the CAD model of the machine into the MCD software. This model was created and given by Renholmen AB. The CAD model, which can be seen in Figure 4, is a virtual representation of the industrial machine Renholmen AB created. The purpose of this machine is to transport wooden planks and to adjust their position before they are cut.

![Figure 4: The orange cylinders and the chains allow the transport of the wooden planks. The mechanism inside the steel box is used to align the incoming wooden planks with centimeter precision.](image)

The chains and cylinders than can be seen in Figure 4 are used to transport wooden planks into an adjustment mechanism before being cut. The cylinders rotate with a constant rotational speed moving the wooden planks towards the adjusting system. The whole mechanism contains one servo motor that controls the movement of the chains and three servo motors that controls the adjusting system. This system can be seen in Figure 5 with the color red, yellow and orange, those are controlled by the motors marked with red ovals.
Figure 5: The motors in the picture marked with red ovals control the movement of the chains and the positioning of the pistons.

The CAD model of the machine consisted of more than three thousand parts. Every part of the model needed to be understood to be able to create a good mechatronic model. To solve this problem an image directory of every part was created and printed. Those images were used as a guide to understanding how the model was assembled. This method was useful because no description of the industrial machine operations was given by Renholmen AB and understanding its functionalities was necessary to recreate the physics of the model in MCD.

The first step in MCD was to define all the parts as rigid bodies. This allowed the parts to be affected by the laws of physics thanks to the physics engine in MCD. Also, different parts were combined into single bodies to simplify the model. Surfaces were also selected from the rigid bodies making it possible to simulate collisions between objects and analyze their behavior virtually. It was important to not select all the surfaces as a collision body due to the computer power needed to simulate increases.

The rigid bodies were attached to each other by the use of joints. MCD has a vast selection of
joints to make components move relative to each other or to fix them in the desired position. For every joint added in the model, it was important to define the direction of the movement or rotation followed by its anchor point. This to ensure that the parts were allocated in the right position in the model. A tool for speed and position control was used to control the servo motors.

To run the simulation and test if the mechatronic model was made correctly a program needed to be written first. The program was written in MCD using a tool called sequence diagram.

4.2 Signal connections

In this project, the connections were established in SIMIT by the use of the couplings reserved for MCD and PLCSIM Advanced. Those couplings can be seen inside the red boxes in Figure 6. The MCD coupling was used to imports all the signals and parameters that were defined in the MCD model. Two different options were available in SIMIT for the import of the signals. Those were "import" and "link to external file". The last-mentioned was the one used in this project. The signals from TIA Portal were imported by using the PLCSIM Advanced coupling. The signals were later mapped by the use of PROFIdrive blocks. This made it possible to establishing a connection between TIA Portal, SIMIT and MCD. The PROFIdrive blocks are explained in more detail in section 4.3.

![Figure 6: The red boxes shows the couplings used in SIMIT to connect the virtual controller (PLC) together with the MCD model of the industrial machine.](image)

4.3 Linking the programs with SIMIT

SIMIT was used for its capability to import signals both from MCD and TIA Portal and connect them using PROFIdrives blocks. Those blocks were used to send, receive and process the incoming
information from TIA Portal and MCD. Some of the information that PROFIdrive2 was responsible for was the calculation of the position and speed of the motors of the industrial machine. The building blocks used in a PROFIdrive are shown in Figure 7. Every component used to construct those blocks are listed below:

- PROFIdrive2
- Sensor
- DynamicServoControl
- MomentumReduction
- SensorProcessRotatory

The components of the PROFIdrive2 calculates the target speed/position and sends the calculations to the MCD model. When those values are received, the model of the industrial machine moves and sends the actual position and speed back to SIMIT. This process repeats every two milliseconds, which is a speed that can be changed depending on the system but was fast enough for this project.

Figure 7: A PROFIdrive is composed of several blocks connected together allowing signals from TIA Portal and MCD to be linked.

The model defined in MCD was composed of four servo motors. Three of those were used for positioning the pistons and one for the movement of the chains, as can be seen in Figure 8. Four PROFIdrive were used to connect and control the servomotors in MCD using SIMIT, one for each servomotor.
The machine has three motors that control the pistons and one motor that controls the chains. The arrows show that the movements are controlled by signals.

It was important to have the same units of measurement in both software. MCD used millimeters and degrees by default but SIMIT uses meters and radians. Millimeters and degrees was considered a better choice for the simulation.

The option "Bus Synchronous" was selected in SIMIT to synchronize the data transfer rate between SIMIT, TIA Portal and MCD.

### 4.4 TIA Portal and visualization

TIA Portal was used to complete several tasks that were essential for this project. A summary of those are described in the following subsections.

#### 4.4.1 Hardware configuration

The hardware configuration for this project was made in TIA Portal by selecting different components. The most important components used for this project were the PLCs of type 1517T-3 PN/DP and the HMI. An HMI is an interface screen used to control a machine or device (62). Also, four different motor drives used for speed and position control were selected and connected to the PLCs. The communication between the components was established by the use of a communication protocol called Profinet. The whole hardware configuration for this project can be seen in Figure

![Figure 8: The machine has three motors that control the pistons and one motor that controls the chains. The arrows show that the movements are controlled by signals.](image-url)
All the four drives needed to be configured based on a specific "telegram" which contained the properties of the motor of the industrial machine. Those telegrams were used to control both speed and position of the motors directly from TIA Portal.

Figure 9: The configuration setup for the whole project used two PLCs, four drives and an HMI.

### 4.4.2 Technology objects

A technology object is a link that enables the configuration of the servo drives. Four different technology objects were created and configured in TIA Portal, each for every servo drive. To ensure that the configuration was made in the right way a test was needed to be done. The motors were tested by the use of an Axis control panel. This panel is a tool integrated into TIA Portal that allowed the possibility to test the motors of the industrial machine. Different velocities were sent to the MCD to ensure that the model moved as intended. The panel used to send the parameters to the motors can be seen in Figure 10.
4.4.3 Motion blocks and programming

Motion blocks are functions that are used to control the motor drives from the program environment in TIA Portal. Several blocks can be used depending on the application. For this project, the blocks MC_Power and MC_Jog were enough for the movement of the motors. The MC_Power allowed the motor drive to be activated and corresponds to the power supply of the motor drive. The MC_Jog were used to received instruction about the motion of the motors. Those instruction were e.g. speed, acceleration, and position to name a few.

The program created in this project was made with the purpose to control the machine both in automatic and manual mode. This type of structure is called HOA and stands for Hand, Off, and Auto. The whole program was made using ladder programming in combination with function blocks. Those programming languages (LAD, FBD) are standards for PLC programming. Figure 11 shows a section of the HOA program made in Tia Portal.
Figure 11: The program in ladder logic diagram shows a section of the code meant to control the machine both automatically and manually.

4.4.4 Human Machine Interface

The visualization of the control panel also referred to as HMI was also created in TIA Portal. This panel was created to control the MCD model in an easier to understand way. By using an HMI it was no longer necessary to open the program code. The most important signals were connected to a screen that showed all the necessary buttons needed to control the model.

The HMI was designed to have different screens in which different components of the machine could be selected. Buttons for navigation were created making it possible to move between different screens. Figure 12 shows one of the displays made for this project.
Figure 12: The figure shows one of several HMI windows that were used to control and observe the movement of the industrial machine.
5 Results of the simulation in the loop

The digital twin made in MCD was able to simulate all the movement needed to control and test the industrial machine from Renholmen AB. It was also possible to simulate the machine in its operational mode. That means that all the four motors were tested at the same time in MCD. The model in MCD was able to read and write the signals from TIA Portal, which means that the real program meant to control the machine could be tested in this way.

The primary job of TIA Portal was to send information about how the servo motors should move (speed, acceleration, and position) into the digital twin. Different parameters were tested to ensure that the mechatronic model worked as intended. The results showed that the data was correctly transferred between all the linked programs. The digital twin of the industrial machine was also able to receive the data and keep the desired speed and position sent to the servo motors. This showed that VC can be used not just to test code but also to trim the control system of the machine.

The results show that a SIL can be a great tool to use to commissioning machines without the need of a real prototype or a real controller. All the connection can be simulated and the speed in which the data will be transfer can also be chosen. This gives VC great opportunities to test and optimize program code.

Design errors were also found by doing the SIL simulation of the industrial machine in this project. A lot of money can be saved if errors are found in the early stages of product development. Also by doing several designs iteration a more optimal design can be found.
6 Discussion

The software used in this project had a lot of tools and it took time to fully learn and understand. Also, a good understanding of the machine was needed before creating its mechatronic twin.

Simple models can be simulated in a short time, however more complex machines require great knowledge and understanding of using those software. There are not many tutorials about SIMIT and MCD and it is necessary to have a solid base before working with those programs. It is also important to have in mind that a SIL uses a lot of computer power to simulate because all the program need to be run in the same computer and in real time.

SIMIT was an essential part of the project for its capability to import the signals needed to run the machine. It was easy to make the connections between MCD and TIA Portal with the help of PROFIdrives. However, a lot of parameters needed to be configured before running the simulation, e.g. the units of measurement which need to match the ones defined in MCD, also parameter as cycle time, encoder resolution and configuration of the PROFIdrives.

TIA Portal was the brain of this project and took about 50% of the time dedicated to this project due to the lack of experience and knowledge. It was challenging to start working in this environment and understand all the steps needed to create a plan with the proper setup. A big part of the knowledge obtained came from forums and tutorials from internet and most of the work was made using a trial and error approach.

Some of the challenges found in TIA Portal was to connect devices and exchange data. The device configuration made in this work uses two PLCs and four different servo drive to control the machine. However, it is possible to obtain the same result using one PLC and fewer drives by using several telegrams in a drive.

It took some time to understand which language was the best for this application. A significant amount of time was consumed by learning how to code in this environment. Ladder programming and function block were the languages used to create the program.

Many challenges appeared while working in this project but every one of those was solved. A big help was the commissioning control panel that was available in TIA Portal, it facilitates the troubleshooting process a lot.
7 Conclusions

As a summary, the project successfully demonstrates the strength of virtual commissioning. With no previous experience in any of the software, a digital twin with realistic behavior was developed. This digital twin was able to be controlled from TIA Portal giving correct values when simulated. This leads to the possibility to test and verify the whole machine and its program at an early stage saving time.

Virtual commissioning showed to be an excellent tool for testing and troubleshooting the behavior and program code of a machine. Depending on the goals, different tasks can be achieved for different purposes. An example can be to demonstrate to costumers how their machine will operate before a prototype built, giving them the possibility to do design changes and test those in a virtual model. Another example is to test safety operations, and different scenarios can be checked to ensure that the machine reacts appropriately according to the safety requirements.

Virtual commissioning has a big potential in the Industry 4.0 revolution, due to the possibilities to increase the cooperation between different departments and made it possible to test ideas before a physical machine was built.

The prototype of the machine simulated in this thesis was presented at a visit to Renholmen AB. It turned out that the company had to do changes in the machine due to a problem in the movement of the chains. Those changes were not included in the CAD model of this project but the same errors were discovered during the SIL simulation. That confirms that design errors can be found before a prototype is built.
8 Further work

During the project, many new ideas came to life. How to do a better configuration, better optimization of devices and networks in TIA Portal and better ways of modeling in MCD, just to name a few among others. Those ideas are meant to help as a guide to obtaining a better result in further work in virtual commissioning.

Starting with TIA Portal, a better configuration could and should be done just by using one PLC and fewer drives. A drive can contain more than one telegram, that means that it can control several motors. Also in the configuration section all the components that will be used in a real project can be added, e.g. power supply, encoders, I/O modules to name a few. This way of configuration will give a more realistic solution.

In this project, just two different programming languages were used to control the model, LAD and FBD, however, several languages are available in TIA Portal and could be used to create more elaborate programs.

The next step that can be taken into consideration is to continue to model another industrial machine in the wood industry and simulate its behavior, e.g., a wood plank could be simulated in MCD to follow its movement and trajectory, and this path could later be recorded which can be a piece of exciting information for the mechanical department.

Also, by increasing the experience using the software described in this thesis will lead to a better result. There are a lot of different tools that can be simulated in all those software, e.g., CAM profiles, simulation of robots, PID control, simulation of pneumatic or hydraulics, to name a few.

Last but not least is to verify the simulation in a real machine or hardware in the loop approach.
References


