Digitization with TIA Portal: Virtual commissioning with SIMATIC and Simulink

Main document: Overview of the two use cases and the Simulink model

SIMATIC S7-PLCSIM Advanced
SIMATIC S7-1500 Open Controller
SIMATIC Target 1500S
Simulink

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1 Introduction

1.1 Overview

The Simulink software\(^1\) from MathWorks is frequently used in automation and controls engineering to simulate processes and create algorithms. The requirement is to simulate the model, the algorithm or the function in a few steps either in a virtual environment with PLCSIM Advanced or, using hardware, via a software controller.

This application example describes the structure of a simulation model with Simulink. With the help of two use cases from the area of digitization, it presents the possibilities and the limitations of validating and simulating the simulation model, both virtually as well as hardware-based with SIMATIC products. The example Simulink model consists of a process simulation and a PID controller.

The complete application example consists of the following documents:

- **Main document**: Overview of the two use cases and the Simulink model (this document).
- **Use case 1**: Connecting Simulink models to SIMATIC PLCSIM Advanced via API\(^2\).
- **Use case 2**: Connecting Simulink models to a SIMATIC S7-1500 software controller via OPC UA\(^3\).

Figure 1-1: Overview of use cases

```
+-------------------+          +-------------------+
| Simulink          |          | Simulink          |
| +-------------------+          +-------------------+  
| PID Controller    |          | Open Controller   |
| +-------------------+          +-------------------+  
| Process model     |          | Use case 1        |
|                   |          | Use case 2        |
```

**Required knowledge**

- Basics of configuration and programming with STEP 7 (TIA Portal)
- Basics of creating models with Simulink

\(^1\) MATLAB and Simulink are registered trademarks of The MathWorks, Inc.

\(^2\) Via a user interface (API), S7-PLCSIM Advanced facilitates interaction with your own C++/C# programs or software.

\(^3\) OPC Unified Architecture (UA), an industrial communication protocol
1.2 Principle of operation

A Simulink-made model of a control loop for a propeller-driven pendulum arm is simulated and optimized in the MATLAB environment. The control loop consists of a control path which maps the physical behavior of the pendulum arm, and a PID controller for positioning the pendulum arm in the specified deflection angle.

The next step provides two use cases (see Figure 1-1) to simulate the process model in conjunction with an S7 CPU.

Use case 1

This use case describes how to control the process model in Simulink with PLCSIM Advanced. For this purpose, communication must be established with the virtual controller from PLCSIM Advanced via the API interface. This is realized by an S-function in Simulink, which is used instead of the PID controller. The Simulink model of the PID controller is coded with the Simulink add-on SIMATIC Target 1500S and is run on the virtual controller.

Use case 2

This use case describes how to control the process model in Simulink with the software controller. For this purpose, communication with the software controller must be established via the OPC UA interface. This is realized by a MATLAB function in Simulink, which is used instead of the PID controller. The Simulink model of the PID controller is coded with the Simulink add-on SIMATIC Target 1500S and is run on the virtual controller.
1.3 Components used

This application example was created with these hardware and software components:

Table 1-1: Software components

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MathWorks online documentation: http://mathworks.com/help/


Table 1-2: Hardware components

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<td>1</td>
<td>6ES7677-2DB42-0GB0</td>
<td>-</td>
</tr>
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</table>

Manual, SIMATIC S7-1500 CPU 150xS

Manual: SIMATIC ET 200SP Open Controller CPU 1515SP PC

This application example consists of the following components:

Table 1-3

<table>
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<th>Components</th>
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</tr>
</thead>
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<td>This document.</td>
</tr>
<tr>
<td>109749187_DIGI_Usecases_TIAV16_PROJ_V20.zip</td>
<td>TIA Portal project for use cases 1 &amp; 2.</td>
</tr>
<tr>
<td>109749187_DIGI_Usecases_Simulink_PROJ_V20.zip</td>
<td>Simulink models for use cases 1 &amp; 2.</td>
</tr>
</tbody>
</table>
2 Engineering

This chapter describes the structure and derivation of the control loop for the propeller-driven pendulum arm for the Simulink simulation.

You can find the finished Simulink model in the included example project under the name "Pendulum_Controlled.slx". The file is located in the folder "Simulink_Main" in the compressed file "109749187_DIGI_Usecases_Simulink_PROJ_V20.zip".

2.1 Control loop

The control loop consists of the control path, which maps the physical behavior of the pendulum arm, and a PID controller.

The control variable of the control loop is the deflection angle $\varphi$ of the pendulum arm. The manipulated variable, force $F$, represents the thrust of the propeller.

Figure 2-1: Control loop

2.1.1 Pendulum model (control path)

So that the arm of the pendulum can be moved to the setpoint position, the thrust force $F$ of the propeller must be greater than or equal to the sum of all counterforces.

Figure 2-2: Pendulum model
The sum of the counterforces is composed of the following forces:

- inertial force \( F_{\text{inertia}} \)
- tangential component of the weight force \( F_{\text{gtan}} \)
- the force of friction \( F_{\text{friction}} \) resulting from the frictional torque \( M_{\text{friction}} \)

### Mathematical derivation

Figure 2-3: Mathematical derivation of the pendulum model

\[
\begin{align*}
F &= F_{\text{gtan}} + F_{\text{inertia}} + F_{\text{friction}} \\
F_{\text{gtan}} &= m \cdot g \cdot \sin(\varphi) \\
F_{\text{inertia}} &= m \cdot r \cdot a = m \cdot l \cdot a \\
F_{\text{friction}} &= \frac{M_{\text{friction}}}{l} = \omega \cdot \frac{c}{l} \\
F &= m \cdot g \cdot \sin(\varphi) + m \cdot l \cdot a + \omega \cdot \frac{c}{l}
\end{align*}
\]

Resulting formula for the angular acceleration:

\[
\dot{\alpha} = \frac{F}{m \cdot l} - \frac{g}{l} \cdot \sin(\varphi) - \omega \cdot \frac{c}{l} - \frac{1}{m \cdot l}
\]

#### 2.1.2 Structure of the pendulum model

Based on the resulting formula for the angular acceleration from Figure 2-3, a recursive state space model for the pendulum is constructed in Simulink.

The angular velocity (\( \omega \)) results from the integration of angular acceleration (\( \alpha \)). The deflection angle (\( \varphi \)) results from the integration of angular velocity.

Figure 2-4 shows the structure of the control path.

- \( \ddot{x} \) = angular acceleration \( \alpha \)
- \( \dot{x} \) = angular velocity \( \omega \)
- \( x \) = deflection angle \( \varphi \)
2.1.3 Real-time behavior of the model

The Simulink function "OPC Config Real-Time" (see Figure 2.5) makes it possible to run the simulation at the same speed that it unfolds in reality. However, this is only a pseudo-real-time and minimal deviations from true time may occur. The deviation depends on the computing power of the computer and cannot be determined or predicted exactly.

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4 The term "real-time" characterizes the operation of information processing systems which can reliably provide certain results within a predefined time span, for example in a fixed time reference.

Source: https://en.wikipedia.org/wiki/Real-time_computing
2.1.4 Selecting the integration method

The following options for integration method are available:

- Forward Euler method
- Backward Euler method
- Bilinear transform (trapezoidal rule)

The bilinear transform yields an average from the forward and backward Euler method.

For selecting the suitable integration method, the damping constant is set to 0 and a constant tangential force is applied to the control path. In this case the controller is commented out. The deflection of the pendulum is monitored in Simulink with the "Scope" function.

With a damping constant equal to 0 and a constant force, a sinewave oscillation is expected for the deflection of the pendulum.
Evaluating the integration method

Figure 2-6: Evaluation of the integration method with "Scope" function

Because the bilinear transformation yields the expected, physically correct behavior of the control path, this method will be selected for the integration. Due to the addition of the discretization error in each calculation step, the forward Euler and backward Euler methods are not suitable for the model. The bilinear transform gives an average between the two methods, thus canceling out the discretization error.
2.2 Controller

Dimensioning of the controller

For the controller’s dimensioning, the empirical dimensioning is applied.

- A small, non-critical value is selected for the amplification $P$, and the integral and differential component set to 0.
- The amplification $P$ is slowly increased until the system oscillates steadily.
- The integral component and differential component are added and slowly increased until the result is acceptable.

Figure 2-7 represents the result of the control loop after the dimensioning of the controller has been performed.

![Figure 2-7: Optimized control loop](image)

The following controller parameters were found in the process:

- Proportional component $P = 2$
- Integral component $I = 0.75$
- Differential component $D = 0.5$
3 Use cases

This chapter gives an overview of the two use cases. All details and instructions can be found in the corresponding detail document on the use case in question.

<table>
<thead>
<tr>
<th>Use case</th>
<th>Title</th>
<th>File name</th>
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<td>109749187_DIGI_Usecases_API_DOC_V20_en.pdf</td>
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<td>2</td>
<td>Connecting Simulink models to a SIMATIC S7-1500 software controller via OPC UA</td>
<td>109749187_DIGI_Usecases.OPC_DOC_V20_en.pdf</td>
</tr>
</tbody>
</table>

3.1 Use case 1

This chapter gives an overview of the connection of Simulink models to SIMATIC PLCSIM Advanced via the user interface API. You can find specifics on use case 1 in the supplied documentation "109749187_DIGI_Usecases_API_DOC_V20_en.pdf".

3.1.1 Principle of operation

Using the Simulink ass-on SIMATIC Target 1500S, the Simulink model of the PID controller is codes and then run with the ODK-capable S7-1500 controller. The closed-loop control in the control path from Simulink is made possible here with the PLCSIM Advanced virtual controller.

SIMATIC Target 1500S generates SCL sources for TIA Portal blocks and thus an SO file, which is uploaded to the controller's integrated web browser. The S7 program calls the SO file.

In Simulink, instead of the PID controller the "S-function" is inserted for communication with SIMATIC S7-PLCSIM Advanced.

Figure 3-1: Simulink model for communicating via PLCSIM Advanced API
Tag exchange between the control path in Simulink and the closed-loop controller in the virtual controller occurs via the PLCSIM Advanced API.

The S-function is called cyclically with the sampling rate $T_s = 20\, ms$. The tags are then read and written at the cycle control point of the virtual controller. The control path is thus supplied every $20\, ms$ with the current values from the virtual controller.

The PID controller runs in the virtual controller in a cyclic interrupt OB with the same cycle time ($20\, ms$) as the sampling rate $T_s$ in Simulink.

Figure 3.2

3.1.2 Advantages of the use case

Linking to Simulink via the API offers you the following advantages:

- Additional options for programming via the API, e.g. pausing the virtual controller at the cycle control point (freeze state)
- Synchronizing to the cycle control point of the virtual controller
- Synchronizing the Simulink model with the virtual time of the virtual controller
- Independent of Simulink, e.g. for setting and testing new controller parameters during a service (e.g. via a web server).

3.1.3 Limitations of the use case

Linking to Simulink via the API has the following limitations:

- Performance highly dependent on the performance of the PC, as PLCSIM Advanced and MATLAB run on one computer.
- No communication in real time
- The simulation of complex paths can extend the cycle time on the controller, thereby deviating from the actual behavior in reality.
3.2 Use case 2

This chapter gives an overview of linking Simulink models to a SIMATIC S7-1500 software controller via OPC UA. You can find specifics on use case 2 in the supplied documentation "109749187_DIGI_Usecases_OPC_DOC_V20_en.pdf".

3.2.1 Principle of operation

Using the Simulink ass-on SIMATIC Target 1500S, the Simulink model of the PID controller is codes and then run with the ODK-capable S7-1500 controller. The closed-loop control in the control path from Simulink is made possible here with the software controller on a SIMATIC ET 200SP Open Controller.

SIMATIC Target 1500S generates SCL sources for TIA Portal blocks and thus an SO file, which is uploaded to the controller’s integrated web browser. The S7 program calls the SO file.

In Simulink, instead of the PID controller the MATLAB function "Read_OPC_Func" is inserted. This function contains the necessary connection parameters to the OPC server of the software controller, as well as the instructions for reading and writing the controller tags.

Figure 3-3: Simulink model for communicating via OPC UA

Tag exchange between the control path in Simulink and the closed-loop controller in the software controller occurs via OPC UA. The MATLAB function is called cyclically with the sampling rate $T_s = 20$ ms. Thus, the closed-loop controller tags are read from and written to the software controller every 20 ms. For this purpose, nodes are defined in the function "Read_OPC_Func" for access to interface tags from the global DB "OpcInterface" in the software controller.

The PID controller runs in the virtual controller in a cyclic interrupt OB with the same cycle time as the sampling rate $T_s = 20$ ms in Simulink.
3 Use cases

3.2.2 Advantages of the use case

Linking to Simulink via OPC UA offers you the following advantages:

- Validation of closed-loop controller parameters before even commissioning with the corresponding hardware
- Controller and Simulink do not run on the same computer
- Independent of Simulink, e.g. for setting and testing new closed-loop controller parameters during a service.

3.2.3 Limitations of the use case

Linking via OPC UA has the following limitations:

- Simulink model runs in pseudo-real-time
- No communication in real time
- No cycle synchronicity between the model in Simulink and the PID controller in the controller. Regardless of the cycle control point, data exchange happens at an undefined point in time.
4 Appendix

4.1 Service and support

Industry Online Support
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support.industry.siemens.com/cs/ww/en/sc/2067
4.2 Industry Mall

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4.3 Links and literature

Table 4-1

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| 1   | Siemens Industry Online Support  
https://support.industry.siemens.com |
| 2   | Link to this entry page of this application example  
| 3   | Target 1500S for Simulink, product page  
http://www.siemens.com/simulink |
| 4   | Target 1500S for Simulink, Industry Online Support site  
https://support.industry.siemens.com/cs/ww/en/ps/6ES7823-1BE03-0YA5 |
| 5   | SIMATIC S7-1200, S7-1500 PID control  
| 6   | Manual: SIMATIC S7-PLCSIM Advanced  
| 7   | MathWorks online documentation:  
http://mathworks.com/help/ |
| 8   | Manual: STEP 7 Professional V16  

4.4 Change documentation

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<td>V2.0</td>
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