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Digitalization with TIA Portal: Virtual Commissioning with SIMATIC and Simulink - Main Document

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

https://support.industry.siemens.com/cs/ww/en/view/109749187

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1 Introduction

1.1 Overview

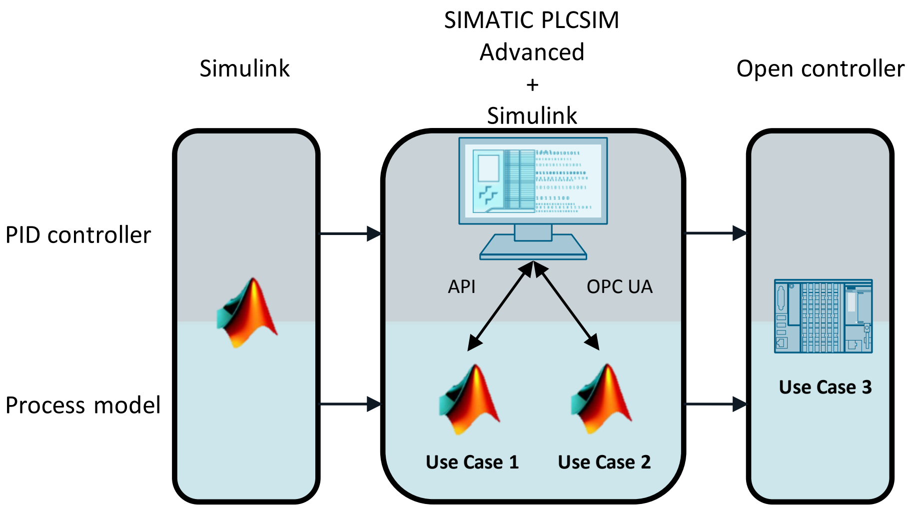
In automation and control engineering, the Simulink[1] software from MathWorks is frequently used to simulate processes and create algorithms. The requirement is to simulate the model, algorithm or function in a virtual environment via PLCSIM Advanced or, based on hardware, using a software controller in just a few steps.

This application example describes how to build a simulation model with Simulink. It uses three digitization use cases to describe the possibilities and limitations of validating and simulating the simulation model virtually and based on hardware with SIMATIC products. The sample Simulink model consists of a process simulation and a PID controller.

The following documents make up the entire application example:

- Main document: Overview of the three 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 SIMATIC PLCSIM Advanced via OPC UA [3]
- Use Case 3: Using SIMATIC Target 1500S for a Hardware-Based Simulation of the Simulink Model

Figure 1-1: Use cases overview



Required knowledge

- Basics of configuring 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 the application programming interface (API), S7-PLCSIM Advanced allows interaction with your own C++/C# programs or software.
[3] OPC Unified Architecture (UA), an industrial communications protocol.

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1.2 How the application example works

A model of a control loop for a propeller-driven pendulum arm that was created using Simulink is simulated and optimized in the MATLAB environment. The control loop consists of a controlled system that emulates the physical behavior of the pendulum arm and a PID controller for positioning the pendulum arm at the specified angle of deflection.

The next step provides three use cases (see Figure 1-1) that allow you 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 using PLCSIM Advanced. This requires that communication with the virtual controller be established via the **API** of PLCSIM Advanced. This is implemented by an S-function in Simulink that is used instead of the PID controller. The “PID Compact” PID controller runs on the virtual controller and can be virtually commissioned in the context of the process simulation in Simulink.

Use Case 2

This use case describes how to control the process model in Simulink using PLCSIM Advanced. This requires that communication with the virtual controller be established via the **OPC UA interface**. This is implemented by a MATLAB function in Simulink that is used instead of the PID controller. The “PID Compact” PID controller runs on the virtual controller and can be virtually commissioned in the context of the process simulation in Simulink.

Use Case 3

This use case describes how to code the Simulink model with the **SIMATIC Target 1500S** Simulink add-on and run it with a SIMATIC S7-1500 Software Controller. The process model is controlled using the “PID Compact” PID controller.

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1.3 Components used

This application example was created with the following hardware and software components:

Table 1-1: Software components

Component	Article number / note / link
(R2016a) MATLAB V9.0 MATLAB Coder V3.1 Simulink V8.7 Simulink Coder V8.10 OPC Toolbox V4.0.1	MathWorks Online Documentation: http://en.mathworks.com/help/
STEP 7 V14 Professional	6ES7822-1..04-.. Manual: https://support.industry.siemens.com/cs/ww/en/view/109742272
SIMATIC S7-1500 ODK 1500S V2.0	6ES7806-2CD02-0YA0 Manual: https://support.industry.siemens.com/cs/ww/en/ps/13914/man
SIMATIC Target 1500S for Simulink V1.0	6ES7823-1BE00-0YA5 Manual: https://support.industry.siemens.com/cs/ww/en/ps/24443/man
S7-PLCSIM Advanced V1.0	6ES7823-1FE00-0YA5 Manual: https://support.industry.siemens.com/cs/ww/en/view/109739153

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Table 1-2: Hardware components

	No.	Article no.	Note
SIMATIC ET 200SP Open Controller CPU 1515SP PC 4GB (WES7-P, 64-bit)	1	6ES7677-2AA40-0AA0	-
	Manual: SIMATIC S7-1500 CPU 150xS https://support.industry.siemens.com/cs/ww/en/view/109249299		
	Manual: SIMATIC S7-1500 Software Controller Additional Information on CPU 1505S/CPU 1507S https://support.industry.siemens.com/cs/ww/en/view/104943430		
	Manual: SIMATIC ET 200SP Open Controller CPU 1515SP PC https://support.industry.siemens.com/cs/ww/en/view/109248384		

This application example consists of the following components:

Table 1-3

Component	Contents
109749187_DIGI_Usecases_MAIN_DOC_V10_en.pdf	This document.
109749187_DIGI_Usecases_API_DOC_V10_en.pdf	Documentation for Use Case 1.
109749187_DIGI_Usecases_OPC_DOC_V10_en.pdf	Documentation for Use Case 2.
109749187_DIGI_Usecases_TARGET_DOC_V10_en.pdf	Documentation for Use Case 3.

Component	Contents
109749187_DIGI_Usecases_TIA_PROJ_V10_en.zip	TIA Portal project for Use Cases 1-3.
109749187_DIGI_Usecases_Simulink_PROJ_V10_en.zip	Simulink models for Use Cases 1-3.

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2 Engineering

This chapter describes how to set up and derive the control loop for the propeller-driven pendulum arm for the simulation with Simulink.

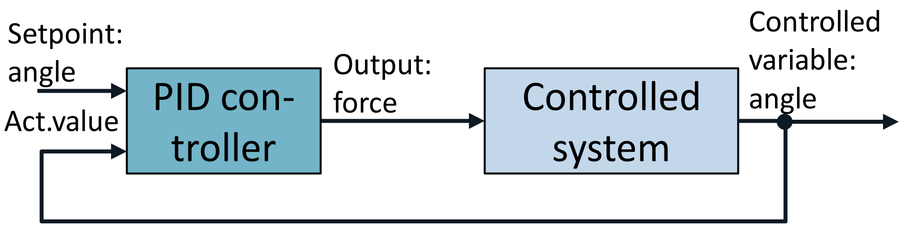
The ready-to-use Simulink model named “Pendulum_Controlled.slx” can be found in the supplied sample project. The file is located in the “Simulink_Main” folder in the “109749187_DIGI_Usecases_Simulink_PROJ_V10_en.zip” file.

2.1 Control loop

The control loop consists of the controlled system that emulates the physical behavior of the pendulum arm and a PID controller.

The controlled variable of the control loop is the angle of deflection (φ) of the pendulum arm. The force (f) drives the propeller forward.

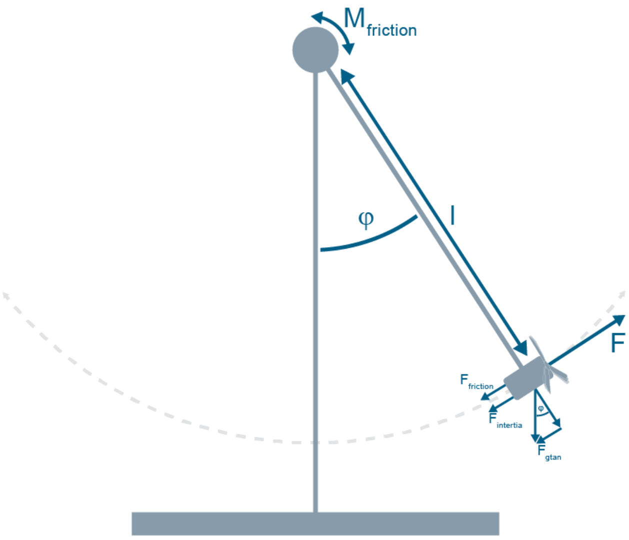
Figure 2-1: Control loop



2.1.1 Pendulum model (controlled system)

For the pendulum arm to be deflected to the setpoint position, the propulsive thrust (F) of the propeller must be at least as large as the sum of all opposing forces.

Figure 2-2: Pendulum model



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The sum of the opposing forces is composed of the following forces:

- Inertial force $F_{intertia}$
- Tangential component of the weight force F_{gtan}
- Friction force $F_{friction}$ resulting from the friction moment $M_{friction}$

Mathematical derivation

Figure 2-3: Mathematical derivation of the pendulum model

$$F = F_{gtan} + F_{intertia} + F_{friction}$$

$$F_{Gtan} = m \cdot g \cdot \sin(\varphi)$$

$$F_{intertia} = m \cdot r \cdot \alpha = m \cdot l \cdot \alpha$$

$$F_{friction} = \frac{M_{friction}}{l} = \omega \cdot \frac{c}{l}$$

$$F = m \cdot g \cdot \sin(\varphi) + m \cdot l \cdot \alpha + \omega \cdot \frac{c}{l}$$

φ: angle
ω: angular velocity
α: angular acceleration
c: damping constant
m: lumped mass
l: arm length
g: position factor

Resulting formula for angular acceleration:

$$\boldsymbol{\alpha = \frac{F}{m \cdot l} - \frac{g}{l} \cdot \sin(\varphi) - \omega \cdot \frac{c}{l} \cdot \frac{1}{m \cdot l}}$$

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2.1.2 Building the pendulum model

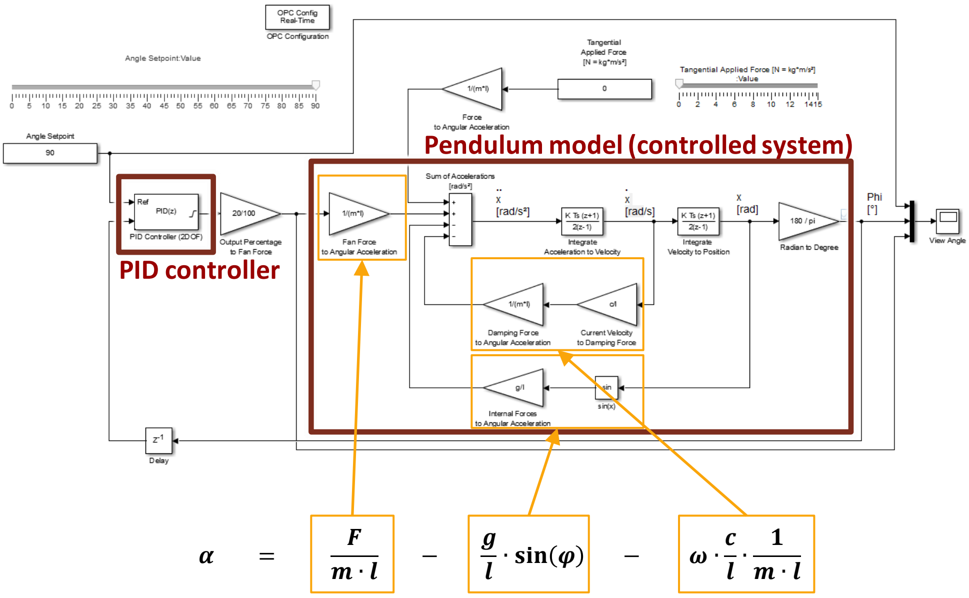
Based on the resulting angular acceleration formula from Figure 2-3, a recursive space state model for the pendulum is built in Simulink.

The angular velocity (ω) results from the integration of the angular acceleration (α). The angle of deflection (φ) results from the integration of the angular velocity.

Figure 2-4 shows the structure of the controlled system.

- $\ddot{x}$ = angular acceleration α
- $\dot{x}$ = angular velocity ω
- x = angle of deflection φ

Figure 2-4: Control loop structure



As parameters for the pendulum model, the following values are specified for the MATLAB variables:

- Damping constant: c = 1
- Lumped mass: m = 2
- Arm length: l = 0.75
- Gravitational acceleration: g = 9.81

2.1.3 Real-time behavior of the model

The “OPC Config Real-Time” Simulink function (see Figure 2-5) allows you to run the simulation simultaneously with reality in terms of time. However, this time is only pseudo real time[4], where minimal deviations from real time can occur. This deviation depends on the computer’s computing power and cannot be exactly determined or predicted.

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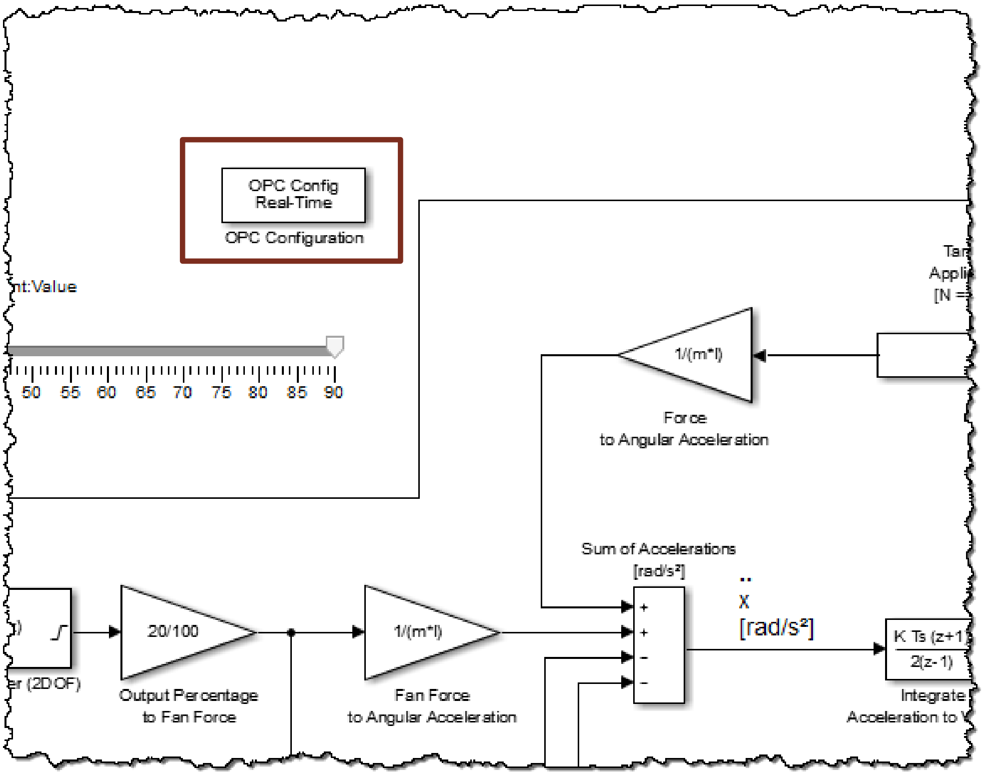
[4] The term ‘real time’ characterizes the operation of IT systems that can reliably provide certain results within a predefined time span, for example in a fixed time frame.
Source: https://de.wikipedia.org/wiki/Echtzeit

Figure 2-5: “OPC Config Real-Time” block



2.1.4 Selecting the integration method

The following integration methods are available for selection:

- Forward Euler
- Backward Euler
- Bilinear transformation (trapezoidal rule)

The bilinear transformation calculates a mean using the forward and backward Euler method.

To select the suitable integration method, the damping constant is set to 0 and a constant tangential force is applied to the controlled system. The controller is commented out. The deflection of the pendulum is monitored in Simulink using the “Scope” function.

When the damping constant equals 0 and there is a constant force, a sinusoidal oscillation is expected for the deflection of the pendulum.

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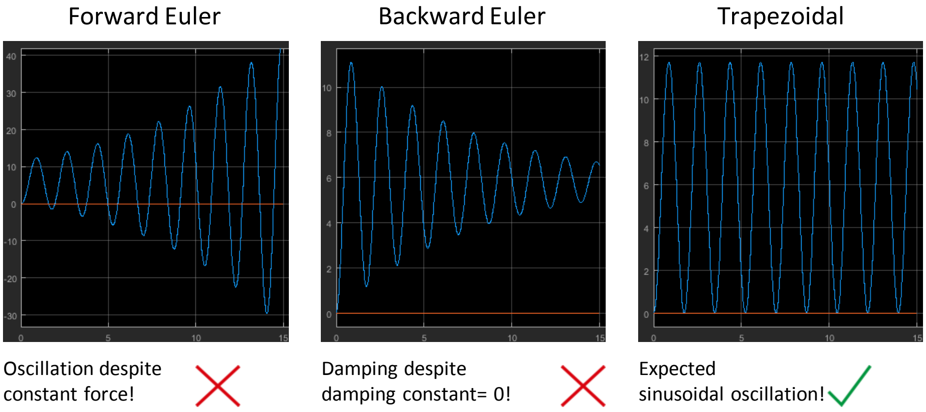
Evaluating the integration method

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



As the bilinear transformation provides the expected, physically correct behavior of the controlled system, this method is selected for the integration.

As they add the discretization error in each step, the forward Euler and backward Euler methods are not suitable for the model. The bilinear transformation calculates a mean using the two methods, which compensates the discretization error.

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2.2 Controller

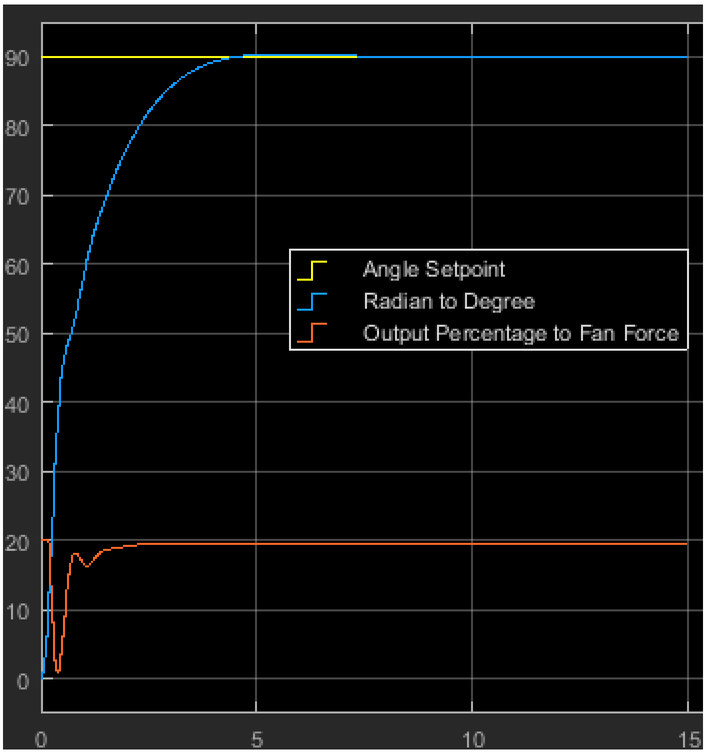
2.2.1 Tuning the controller

Empirical tuning is used to tune the controller.

- A noncritical, small value is chosen for the P gain and the integral-action and derivative-action components are set to 0.
- The P gain is slowly increased until the system constantly oscillates.
- The integral-action and derivative-action components are added and slowly increased until the result is acceptable.

Figure 2-7 shows the result of the control loop after the controller has been tuned.

Figure 2-7: Optimized control loop



The following controller parameters were determined:

- Proportional component P = 2
- Integral-action component I = 0.75
- Derivative-action component D = 0.5

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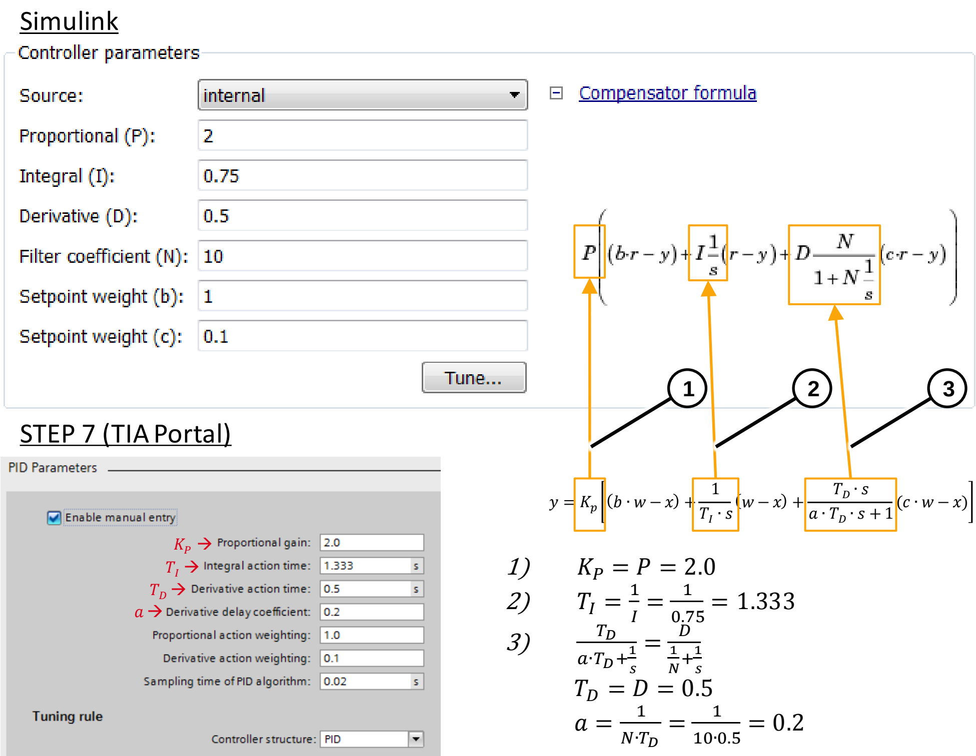
2.2.2 Converting the parameters for PID Compact

The following figure shows the conversion of the controller parameters from Simulink to parameters for PID Compact in TIA Portal.

Figure 2-8



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3 Use Cases

This chapter provides an overview of the three use cases.

For all the details and instructions, refer to the detailed document for the appropriate use case.

Table 3-1

Use case	Title	File name
1	Connecting Simulink models to SIMATIC PLCSIM Advanced via API	109749187_DIGI_Usecases_API_DOC_V10_en.pdf
2	Connecting Simulink models to SIMATIC PLCSIM Advanced via OPC UA	109749187_DIGI_Usecases_OPC_DOC_V10_en.pdf
3	Using SIMATIC Target 1500S for a Hardware-Based Simulation of the Simulink model	109749187_DIGI_Usecases_TARGET_DOC_V10_en.pdf

3.1 Use Case 1

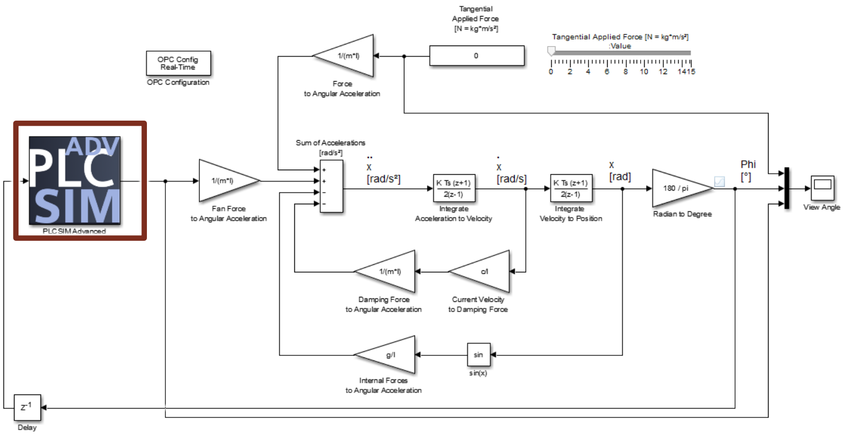
This chapter provides an overview of connecting Simulink models to SIMATIC PLCSIM Advanced via the API application programming interface. For details about Use Case 1, refer to the supplied documentation: “109749187_DIGI_Usecases_API_DOC_V10_en.pdf”

3.1.1 How the use case works

In this use case, the controlled system is controlled from Simulink using the PID controller (PID_Compact) in the virtual controller of PLCSIM Advanced.

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

Figure 3-1: Simulink model for communication via the PLCSIM Advanced API



The tag exchange between the controlled system in Simulink and the controller in the virtual controller takes place via the API of PLCSIM Advanced.

The S-function is called in the cycle of the sampling rate Ts = 20 ms. The tags are then read/written at the cycle check point of the virtual controller. As a result, the

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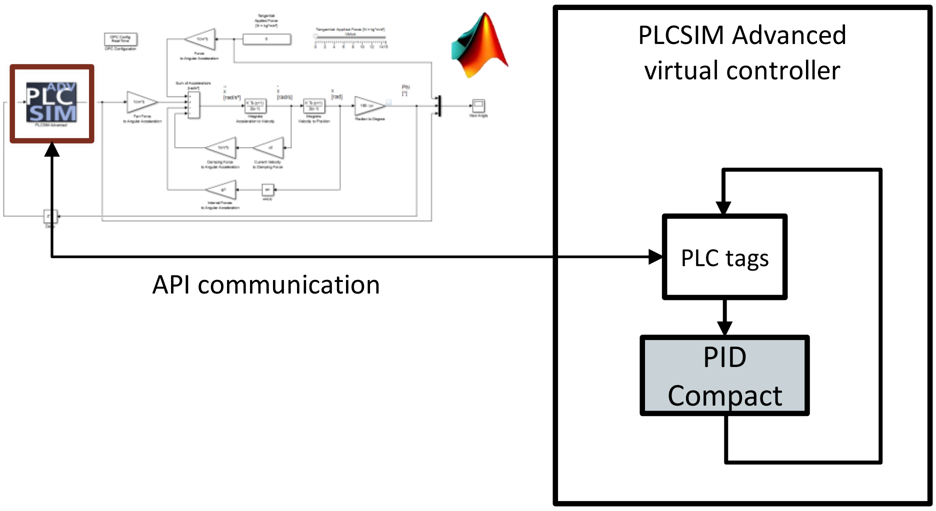
controlled system is provided with the latest values from the virtual controller every 20 ms.

The PID controller runs in the virtual controller in a cyclic interrupt OB with a cycle time (20 ms) that is identical to the sampling rate Ts in Simulink.

Figure 3-2



3.1.2 Advantages of the use case

The connection to Simulink via the API offers the following advantages:

- Advanced programming options via the API such as freezing the virtual controller at the cycle check point.
- Synchronization with the cycle check point of the virtual controller.
- Synchronization of the Simulink model with the virtual time of the virtual controller. When speeding up/slowing down the virtual time, Simulink's pseudo real time speeds up/slows down accordingly.

3.1.3 Limits of the use case

The connection to Simulink via the API has the following limits:

- Performance strongly depends on the PC's computing power as PLCSIM Advanced and MATLAB run on one computer.
- No communication in real time

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3.2 Use Case 2

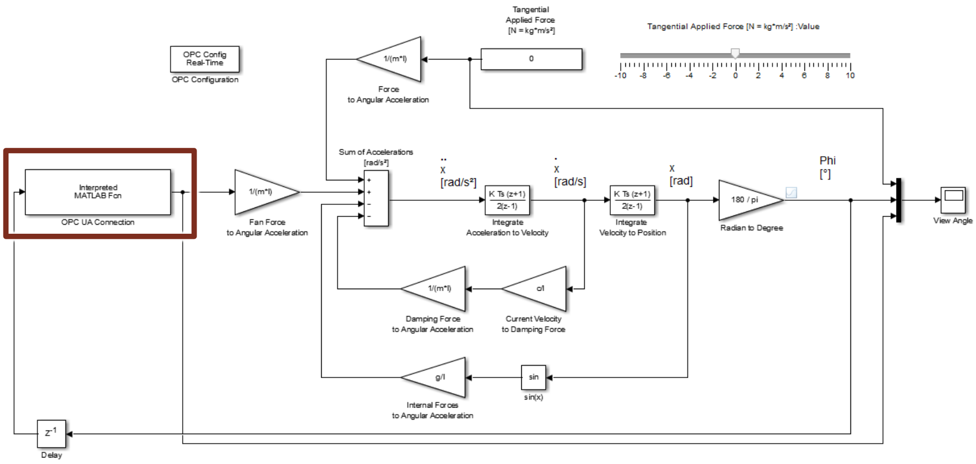
This chapter provides an overview of connecting Simulink models to SIMATIC PLCSIM Advanced via OPC UA. For details about Use Case 2, refer to the supplied documentation: "109749187_DIGI_Usecases_OPC_DOC_V10_en.pdf"

3.2.1 How the use case works

In this use case, the controlled system is controlled from Simulink using the PID controller (PID_Compact) in the virtual controller of PLCSIM Advanced.

In Simulink, the "Read_OPC_Func" MATLAB function is inserted instead of the PID controller. This function includes the required connection parameters for the OPC server of the virtual controller and the instructions for reading/writing the controller tags.

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



The tag exchange between the controlled system in Simulink and the controller in the virtual controller takes place via OPC UA. The MATLAB function is called in the cycle of the sampling rate Ts = 20 ms. As a result, read/write of the controller tags from the virtual controller takes place every 20 ms. To this end, nodes for access to interface tags from the global DB, "OpcInterface", of the virtual controller are defined in the "Read_OPC_Func" function.

The PID controller runs in the virtual controller in a cyclic interrupt OB with a cycle time (20 ms) that is identical to the sampling rate Ts = 20 ms in Simulink.

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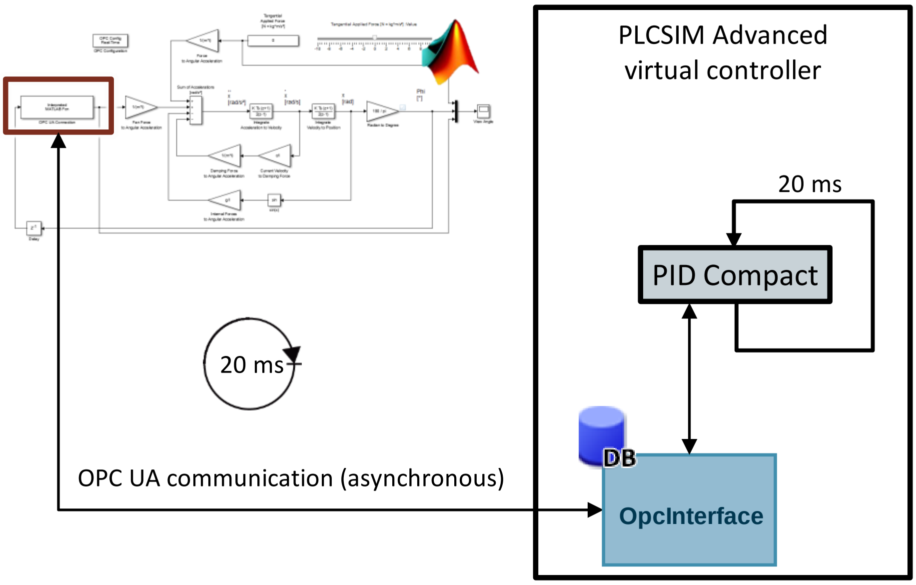
Figure 3-4



3.2.2 Advantages of the use case

The connection to Simulink via OPC UA offers the following advantages:

- Validation of controller parameters already before commissioning with appropriate hardware.
- The parameter settings and the program of the virtual controller can be transferred to a hardware controller (e.g., S7-1500) without any changes to test also this controller in the context of the simulation model.
- PLCSIM Advanced and Simulink can run on different computers.

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3.2.3 Limits of the use case

The connection via OPC UA has the following limits:

- Simulink model runs in pseudo real time.
- No communication in real time.
- No isochronous mode between the model in Simulink and the PID controller in the controller. Regardless of the cycle check point of the virtual controller, data exchange takes place at an undefined time.
- No synchronization with the virtual time of PLCSIM Advanced. When speeding up/slowing down the virtual time of the virtual controller, qualitative control of the model is no longer possible.

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3.3 Use Case 3

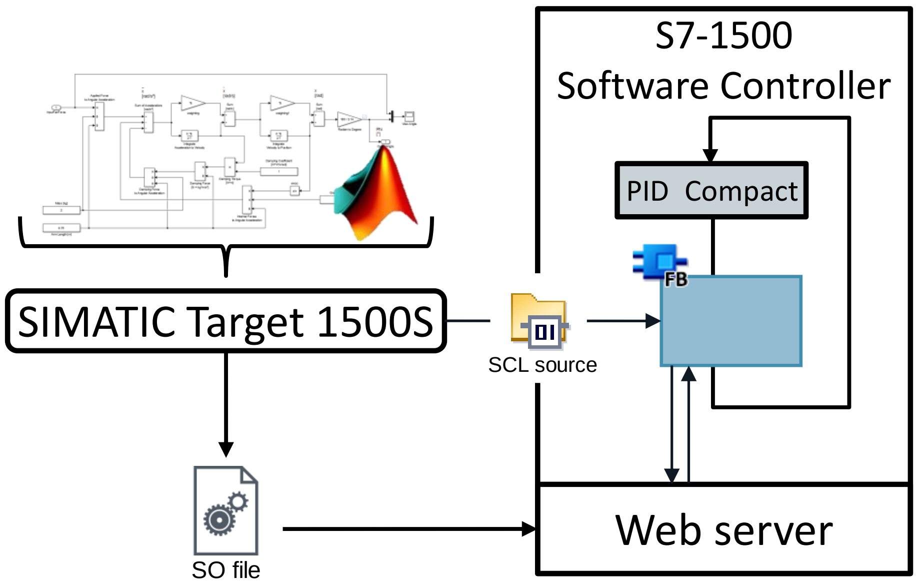
This chapter provides an overview of using SIMATIC Target 1500S for a hardware-based simulation of the Simulink model. For details about Use Case 3, refer to the supplied documentation:
"109749187_DIGI_Usecases_TARGET_DOC_V10_en.pdf"

3.3.1 How the use case works

The Simulink model of the controlled system is coded using the SIMATIC Target 1500S Simulink add-on and run with the ODK-capable S7-1500 controller. The controlled system is controlled by the PID controller (PID Compact) in the controller.

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

Figure 3-5

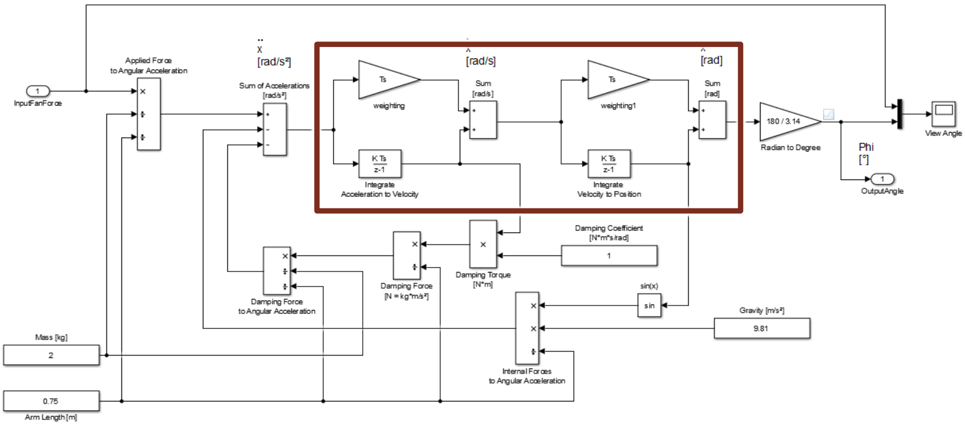


Running the controlled system in cyclic mode of a SIMATIC S7-1500 controller requires that the integration method of the recursive controlled system be changed.

The bilinear transformation cannot be used as, due to the backward Euler method part, it includes an implicit solution of the equation. This is not possible in a cyclic execution of the STEP 7 program.

For an explicit solution of the equation, a weighted forward Euler method is used instead. Figure 3-6 shows the modified controlled system.

Figure 3-6: Modified controlled system



3.3.2 Advantages of the use case

Running the model in conjunction with the controller on the controller offers the following advantages:

- Controller and model are fully synchronous as both are processed in the same cycle
- Change of simulation parameters using the S7 program
- Independent of Simulink, for example, for setting and testing new controller parameters during a service or when changing model parameters
- Real-time communication between controller and model
- Simulink External mode allows you to monitor the model transferred to the S7 controller during operation and change parameters online.

3.3.3 Limits of the use case

Due to the sequence structure of an S7 controller, a trapezoidal rule cannot be used for the recursive controlled system. Instead, the weighted forward Euler method must be used as a workaround.

Especially the simulation of complex controlled systems can extend the cycle time on the controller and thus deviate from the actual real behavior.

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4 Appendix

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https://support.industry.siemens.com/cs/ww/en/sc/2067

4.2 Links and literature

Table 4-1

No.	Topic
\1\	Siemens Industry Online Support https://support.industry.siemens.com
\2\	Link to the entry page of the application example https://support.industry.siemens.com/cs/ww/en/view/109749187
\3\	Target 1500S for Simulink, product page http://www.siemens.com/simulink
\4\	Target 1500S for Simulink, Industry Online Support page https://support.industry.siemens.com/cs/ww/en/ps/6ES7823-1BE00-0YA5
\5\	SIMATIC S7-1200, S7-1500 PID Control https://support.industry.siemens.com/cs/ww/en/view/108210036
\6\	Manual: SIMATIC S7-PLCSIM Advanced https://support.industry.siemens.com/cs/ww/en/view/109739153
\7\	MathWorks Online Documentation: http://en.mathworks.com/help/
\8\	Manual: STEP 7 V14 Professional https://support.industry.siemens.com/cs/ww/en/view/109742272

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4.3 Change documentation

Table 4-2

Version	Date	Modifications
V1.0	12/2017	First version