MATLAB EXPO
FRANCE

8 octobre 2024 | Paris

"Virtual Commissionning" :

Accélérez la mise en service de vos systèmes grâce au Jumeau Numérique

Kevin Roblet,
MathWorks

Morgan Fremovici,
MathWorks

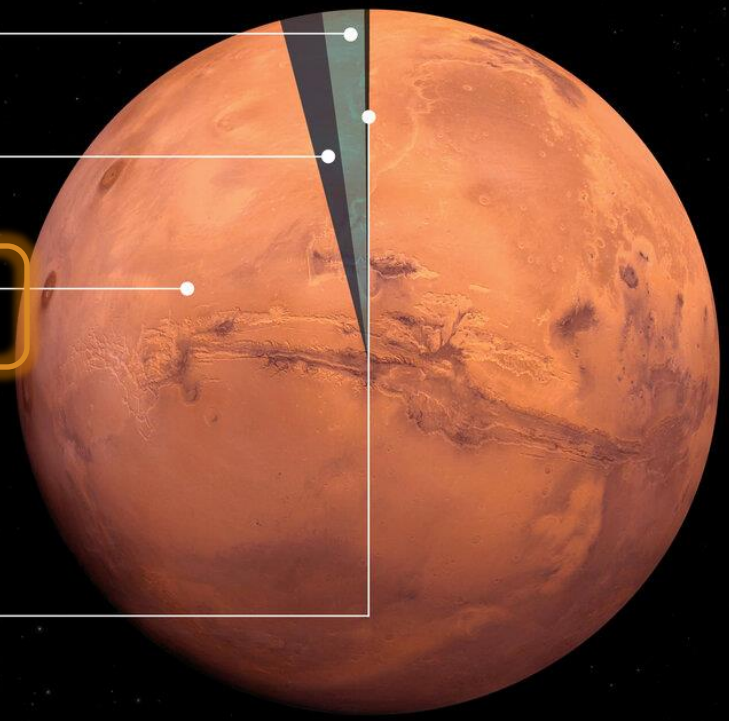
MathWorks

-63°C

225 millions km

CO2 is the solution...

→ COMPARING THE ATMOSPHERES OF MARS AND EARTH



ARGON
1.9%

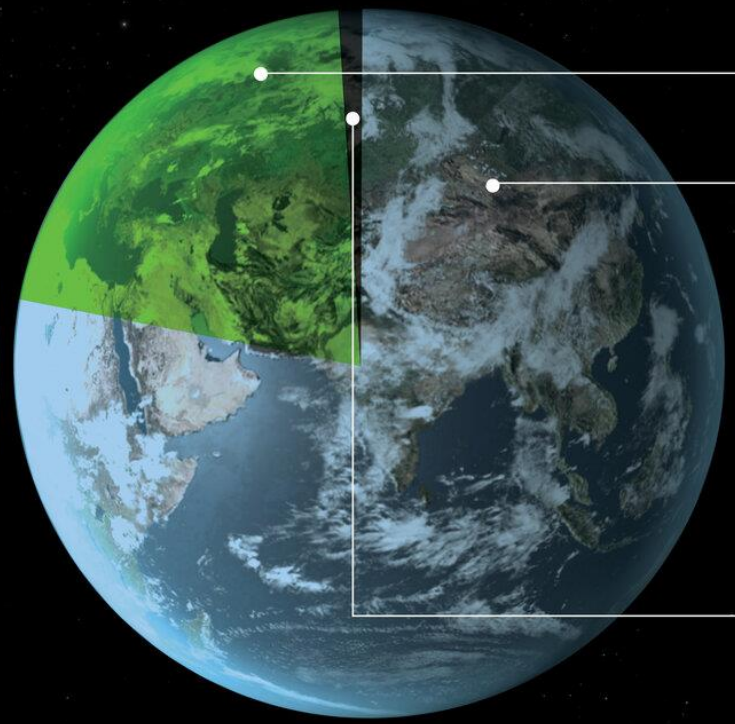
NITROGEN
1.9%

CARBON DIOXIDE
96%

TRACE GASES, INCLUDING:

ACETYLENE
CARBON MONOXIDE
KRYPTON
METHANE
NEON
NITROGEN OXIDE
OXYGEN
OZONE
WATER VAPOUR
XENON

MARS



OXYGEN
20.9%

NITROGEN
78.1%

TRACE GASES, INCLUDING:

ARGON (0.93%)
CARBON DIOXIDE
HELIUM
HYDROGEN
KRYPTON
METHANE
NEON
NITROUS OXIDE
OZONE
SULPHUR DIOXIDE
WATER VAPOUR
XENON

EARTH

Atmospheric composition by volume | Planets not to scale | Atmosphere of Mars is less than 1% of Earth's | Trace gases listed alphabetically

MOXIE

$$CO_2 + 2e^- \rightarrow CO + O^=$$

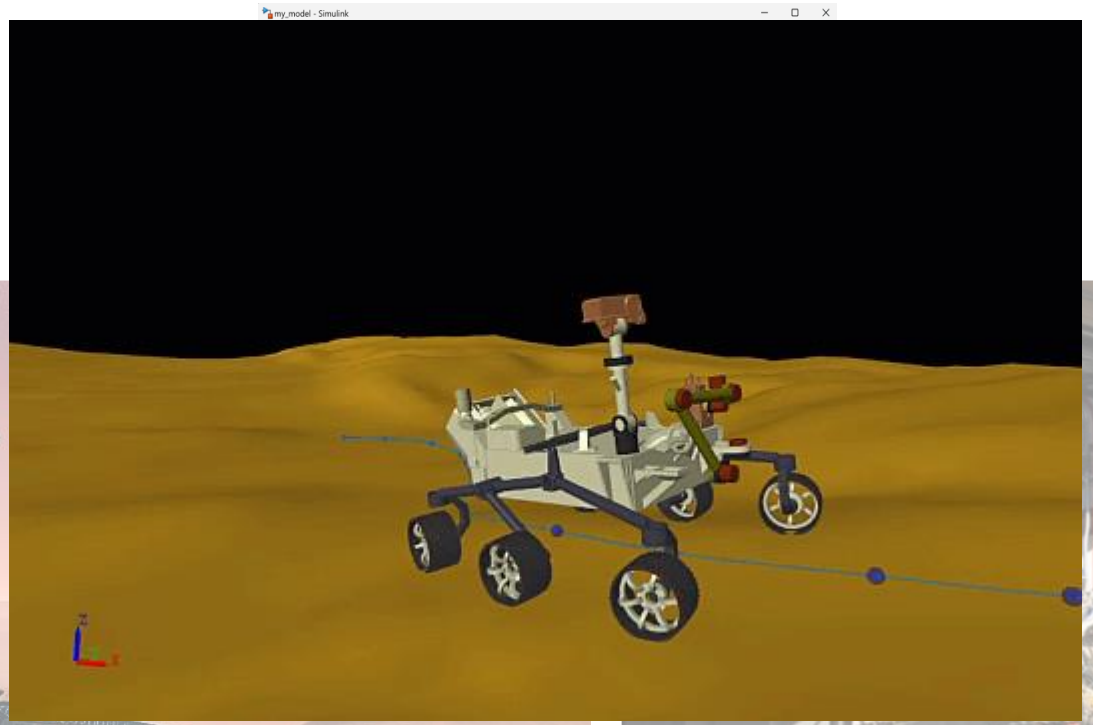
> “If we break something on Mars, you can’t send anybody to go fix it, and you’re done…“

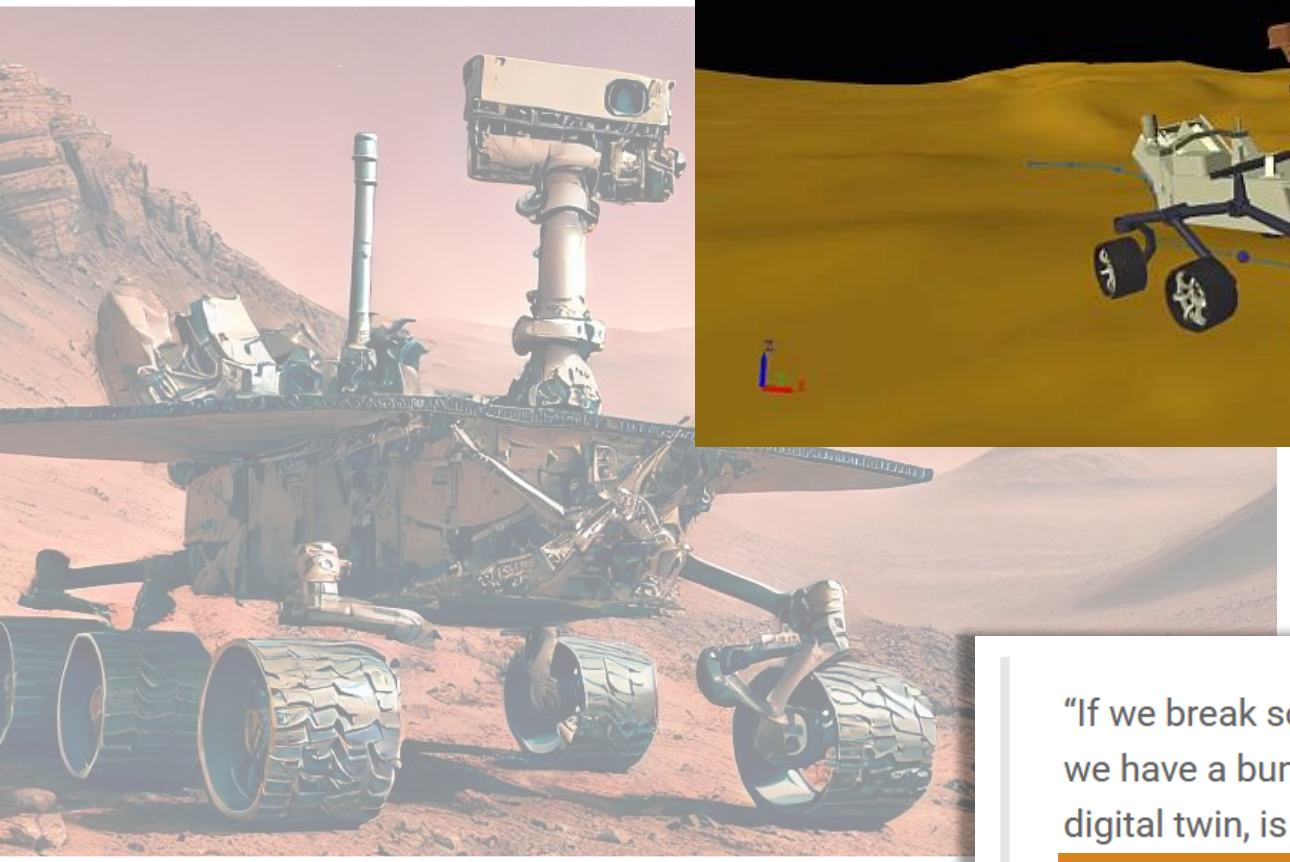
source: generated with ChatGPT

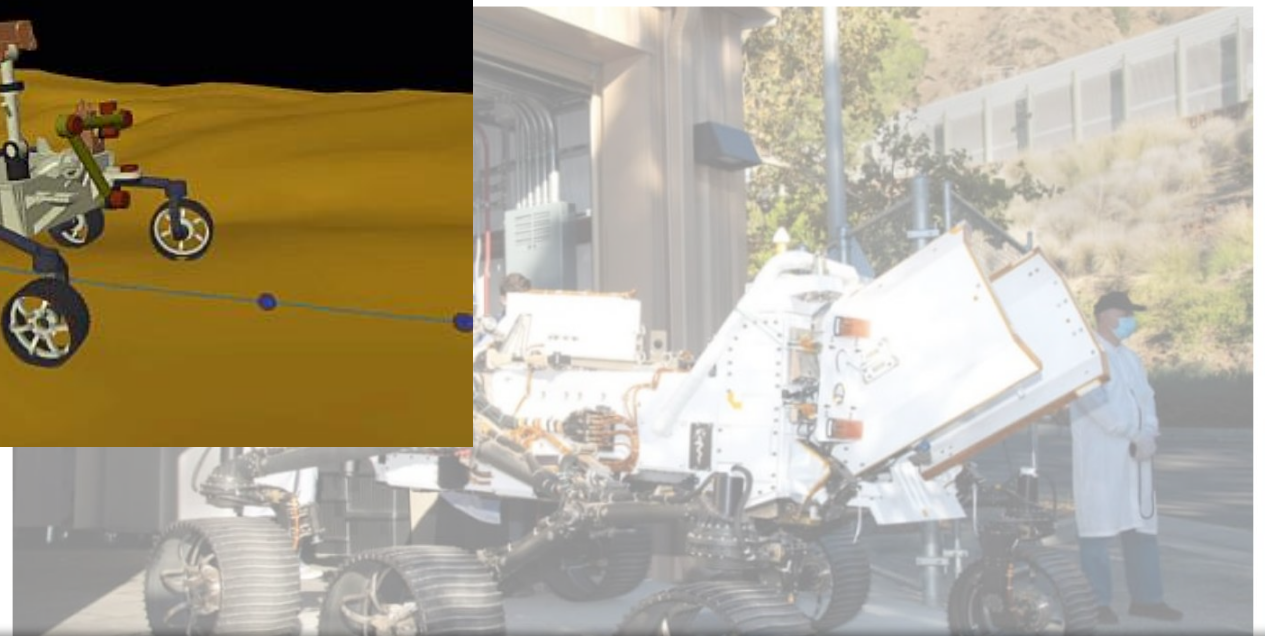
Early Twin Offers Test Bed for **NASA's Perseverance Mars Rover**

The Earthly twin of NASA's Perseverance Mars rover arrives at the Mars Yard garage at the agency's Jet Propulsion Laboratory

https://www.techbriefs.com/component/content/article/40773-earthly-twin-offers-test-bed-for-nasa-s-perseverance-mars-rover







> “If we break something on Mars, you can’t send anybody to go fix it, and you’re done. So, we have a bunch of steps so that we’re pretty confident, and the computer model, the digital twin, is one of those key steps.”
>
> — *Eric Hinterman, doctoral student in the MIT AeroAstro department*

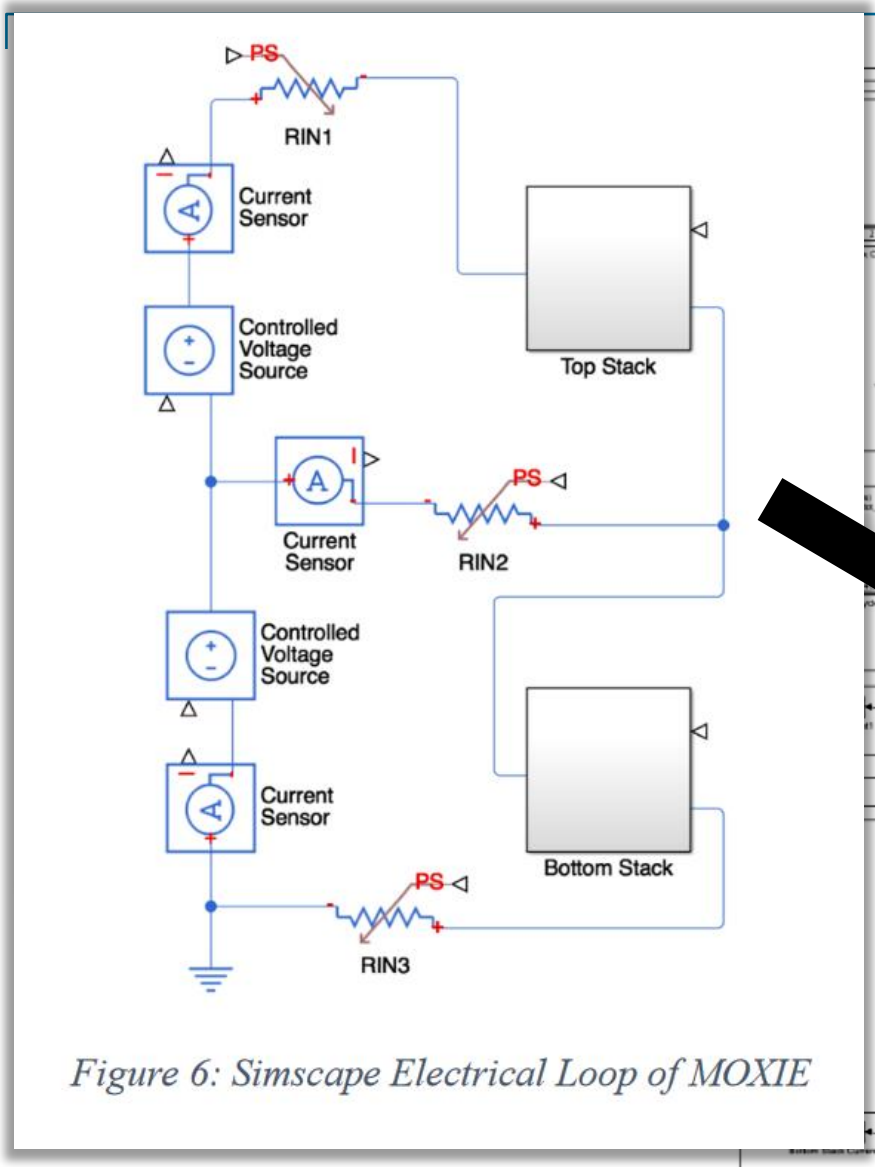
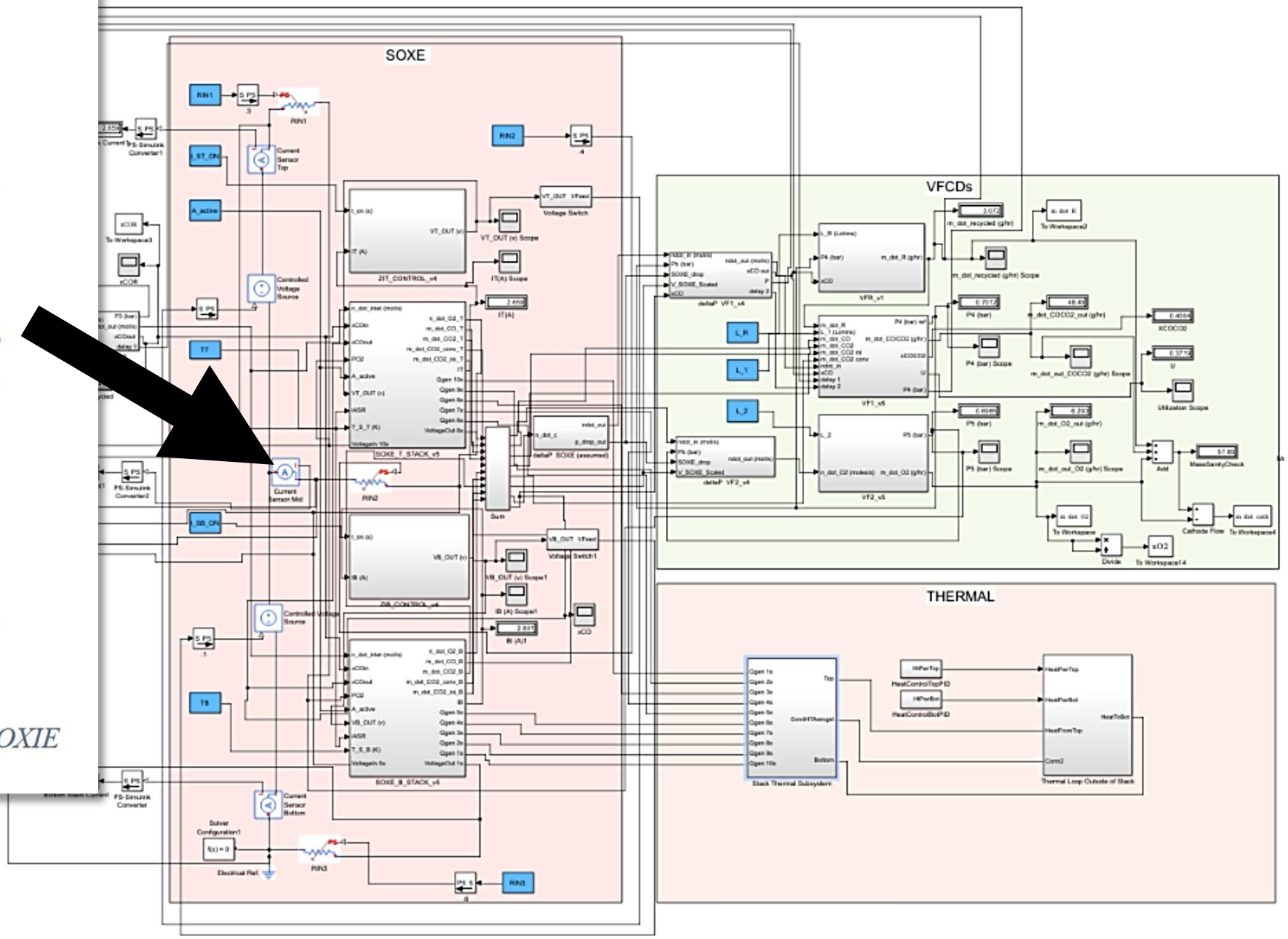


Figure 6: Simscape Electrical Loop of MOXIE



https://www.mathworks.com/company/mathworks-stories/moxie-converts-mars-co2-to-oxygen.html

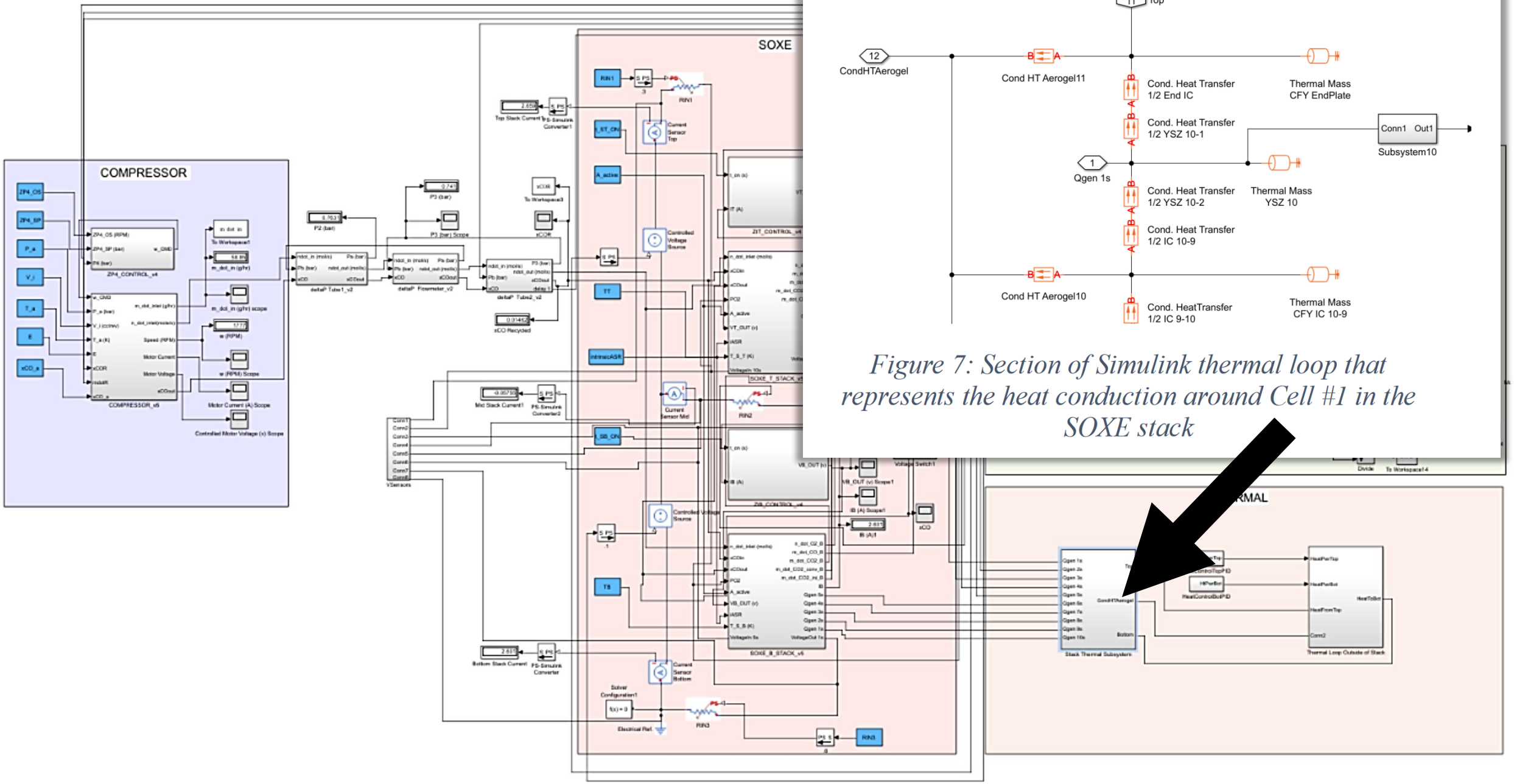
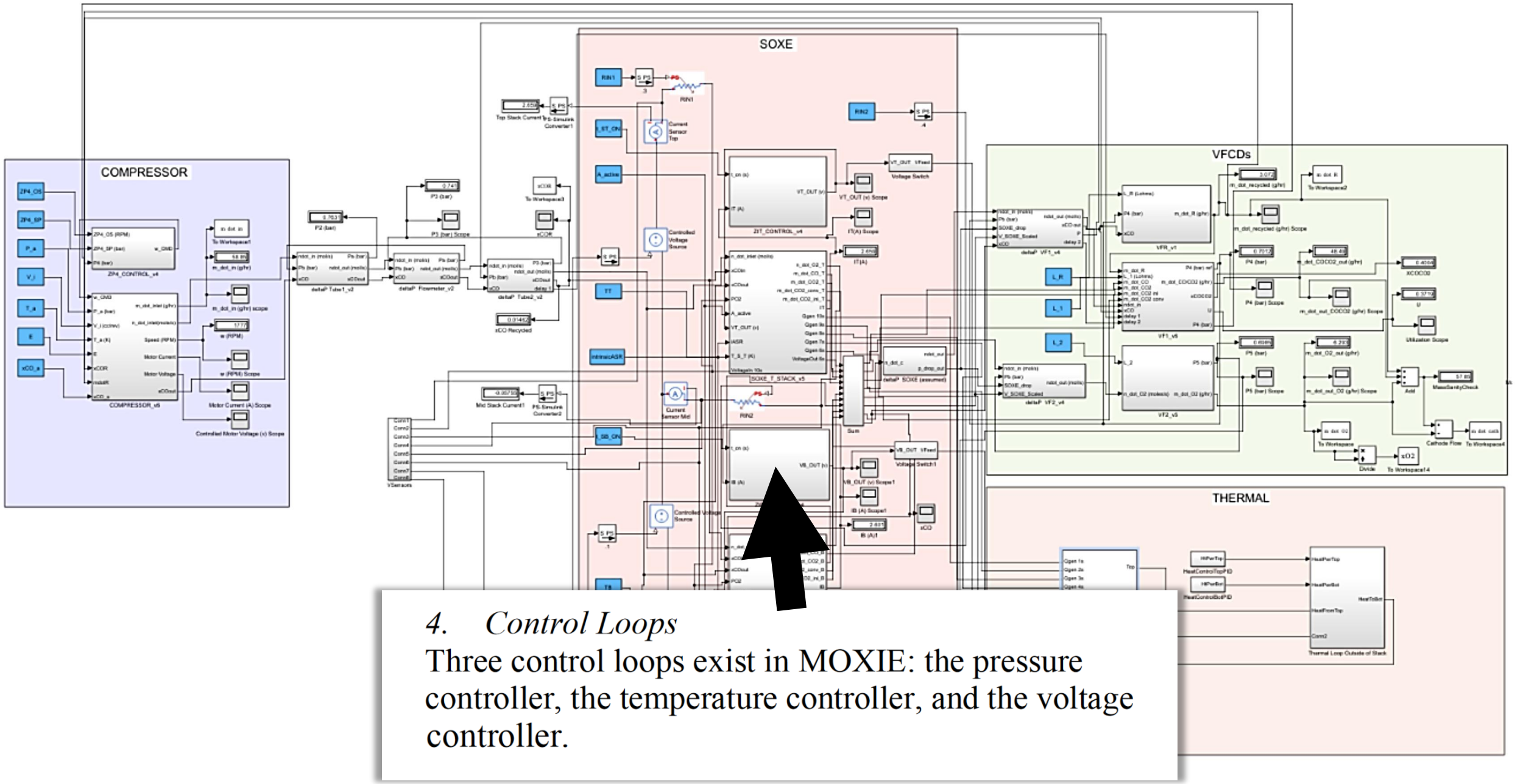


Figure 7: Section of Simulink thermal loop that represents the heat conduction around Cell #1 in the SOXE stack

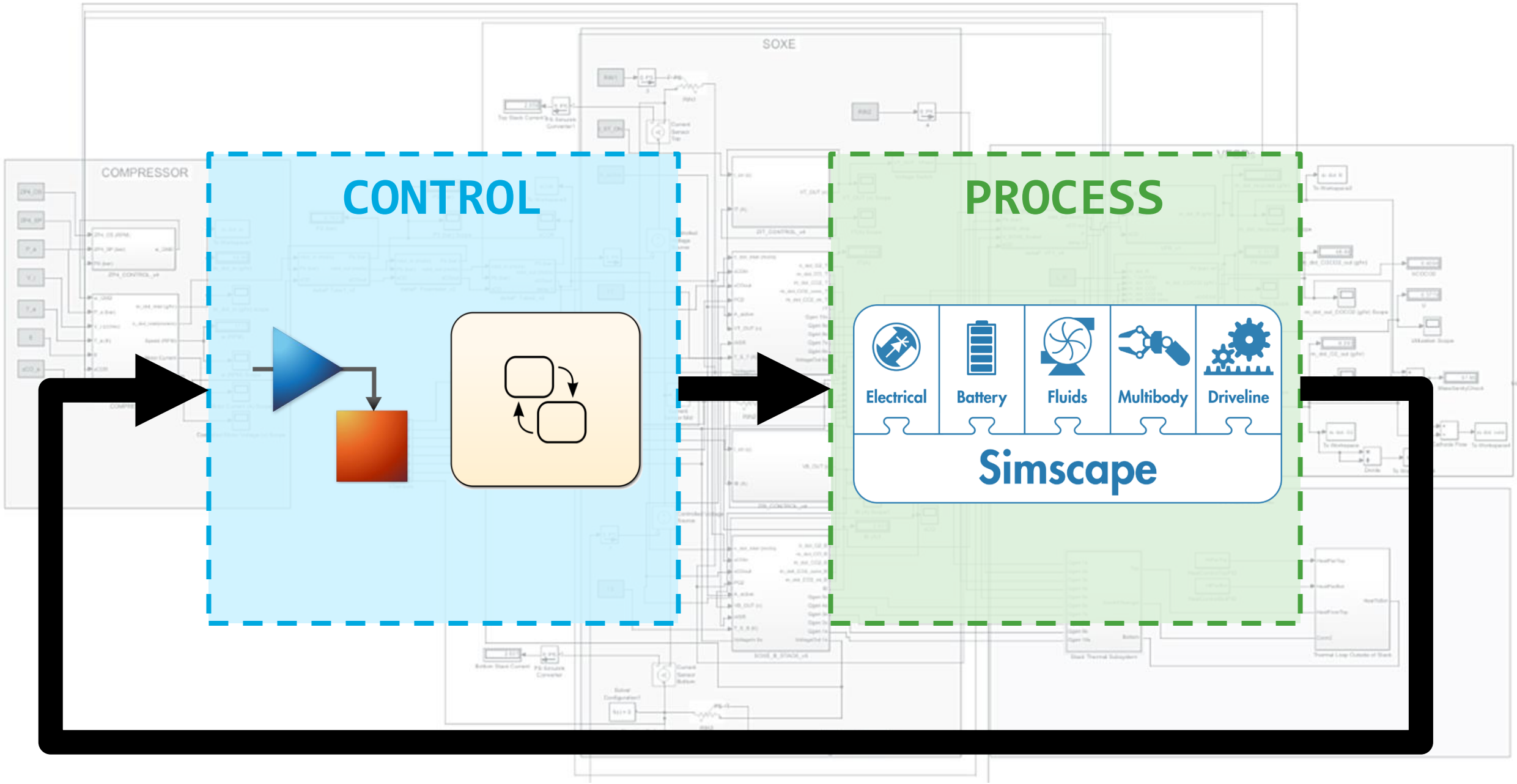
https://www.mathworks.com/company/mathworks-stories/moxie-converts-mars-co2-to-oxygen.html

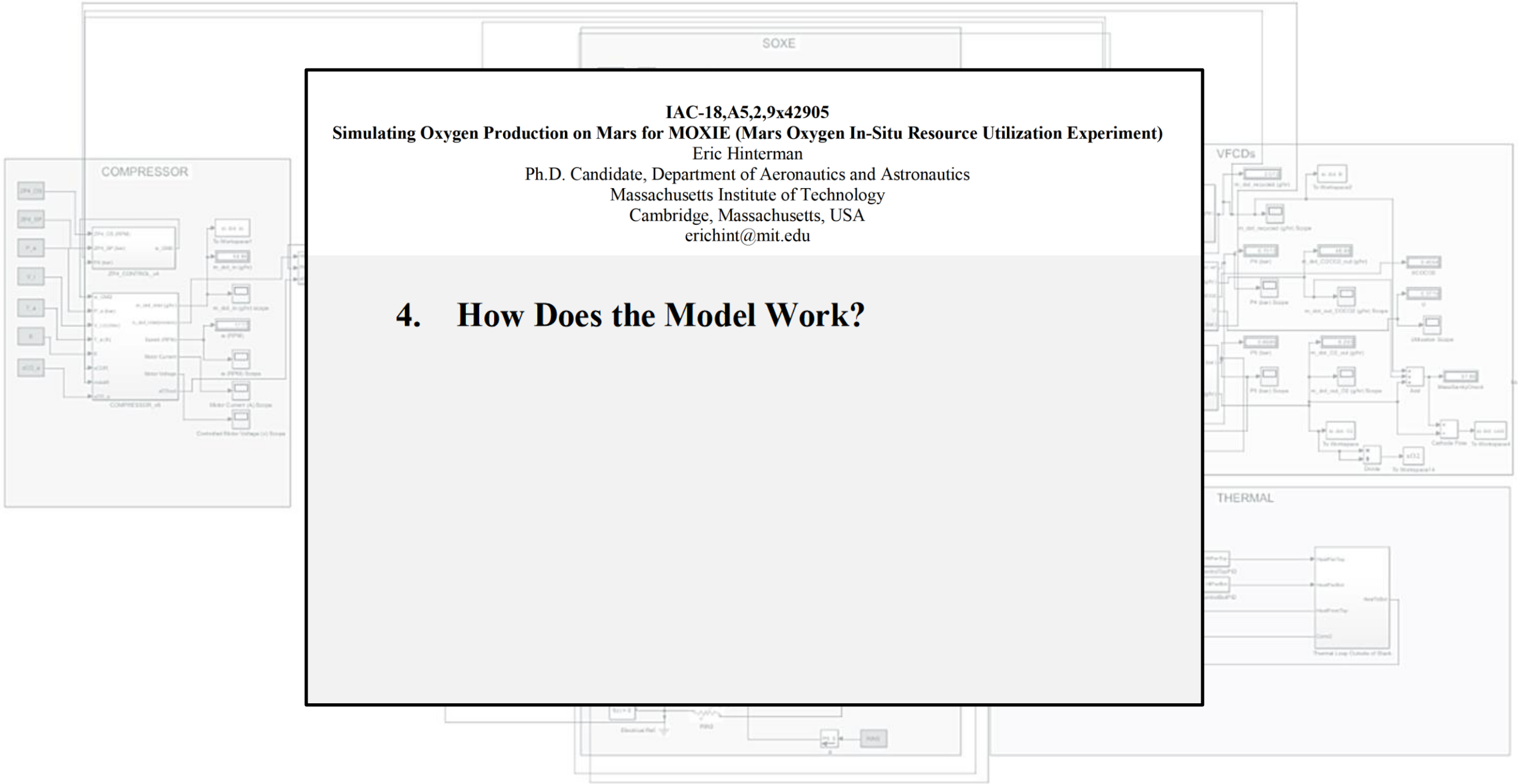


4. Control Loops

Three control loops exist in MOXIE: the pressure controller, the temperature controller, and the voltage controller.

https://www.mathworks.com/company/mathworks-stories/moxie-converts-mars-co2-to-oxygen.html


SOXE
COMPRESSOR
CONTROL
PROCESS
Electrical
Battery
Fluids
Multibody
Driveline
Simscape



IAC-18,A5,2,9x42905

Simulating Oxygen Production on Mars for MOXIE (Mars Oxygen In-Situ Resource Utilization Experiment)

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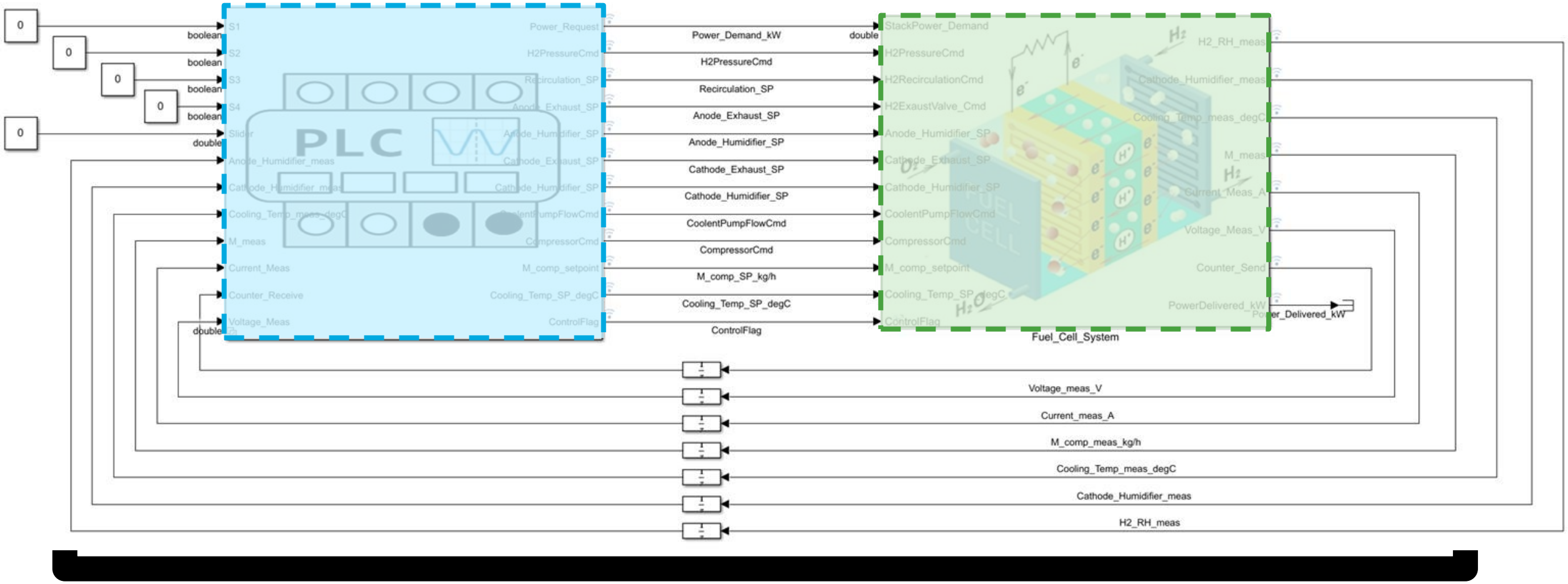
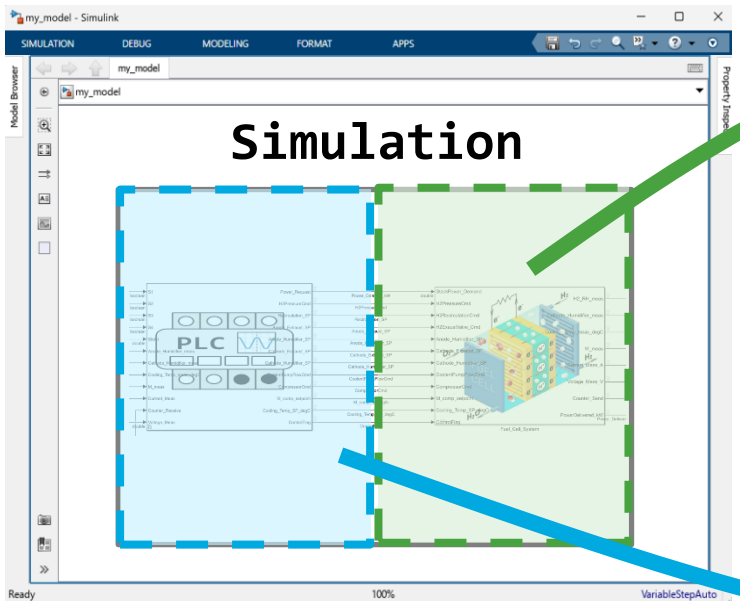
Ph.D. Candidate, Department of Aeronautics and Astronautics
Massachusetts Institute of Technology
Cambridge, Massachusetts, USA
erichint@mit.edu

4. How Does the Model Work?

CONTROL

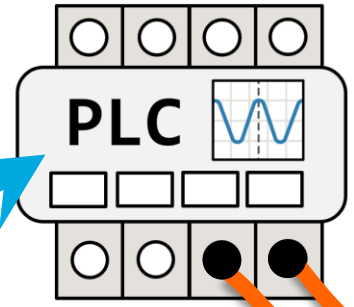
PROCESS





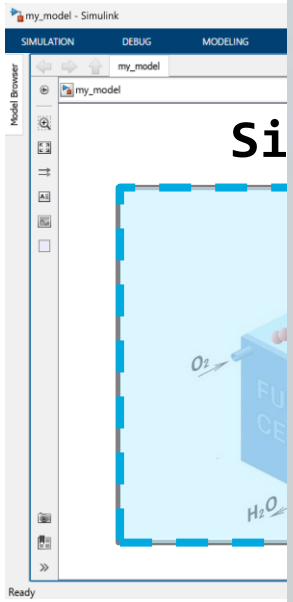
CONTROL + PROCESS

automatic code generation



Real-time Test

DIGITAL TWIN



Si

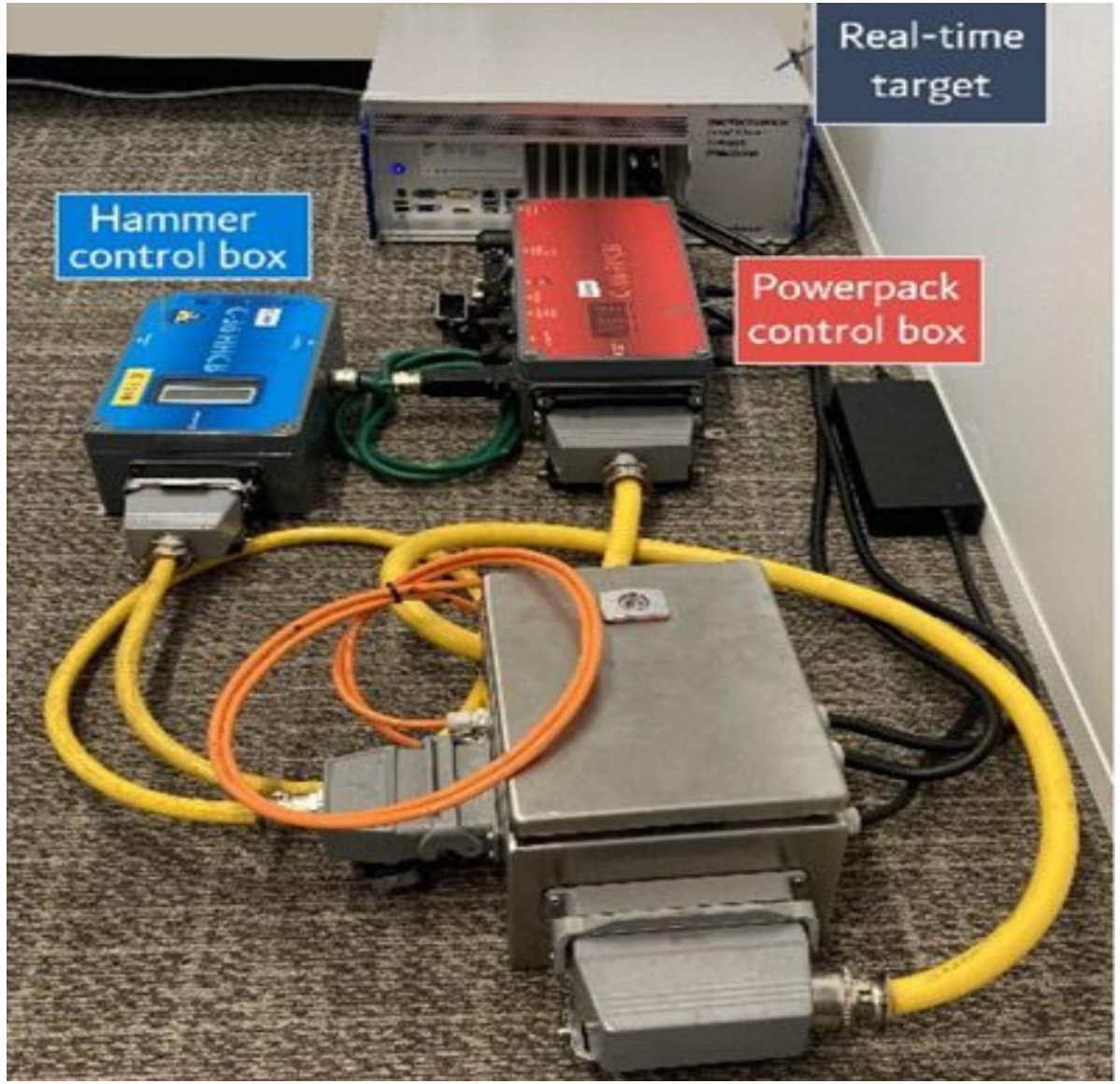
CONTRO

t

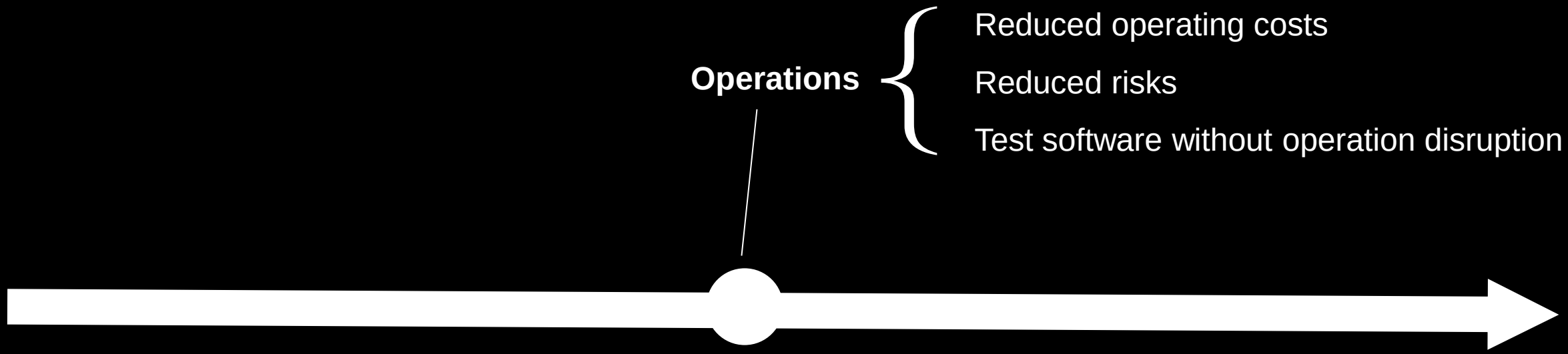
IN

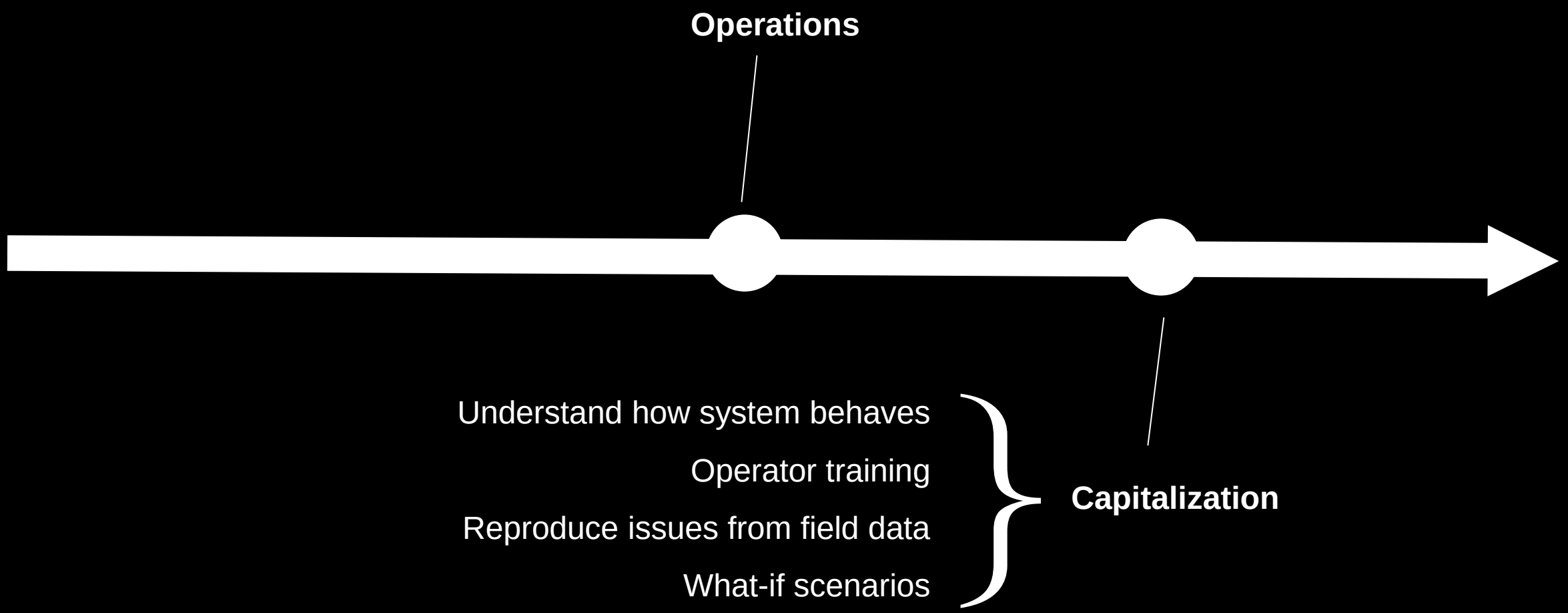
"Without the HIL system, operator training was performed with an actual Hydrohammer, which is costly. With the HIL system, we can now simulate all sorts of faults occurring in reality in the field. On an actual pile driving machine, many of them would lead to damage."

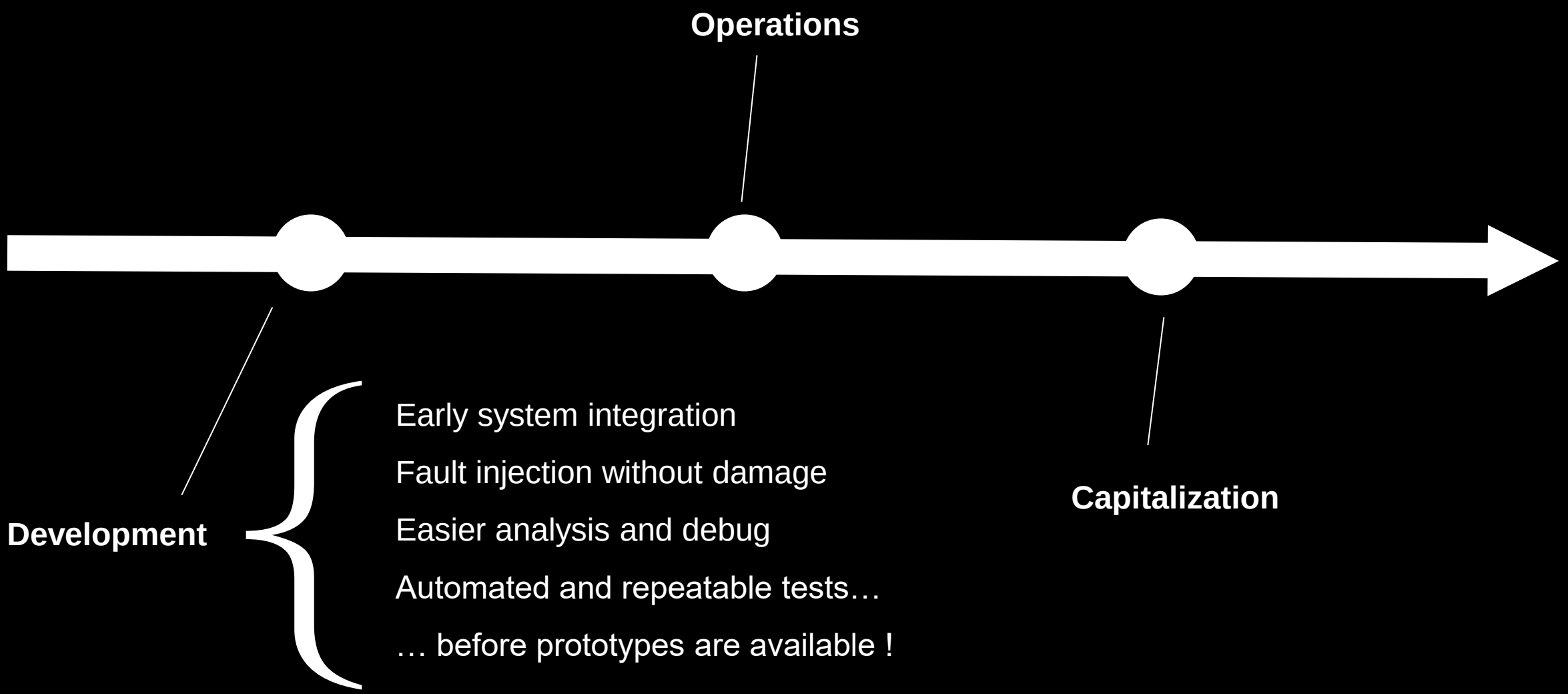
— *Michael Schaap, technical director, IQIP*

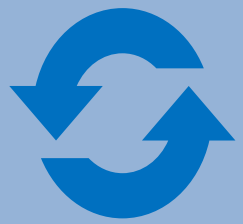


https://www.mathworks.com/company/user_stories/iqip-uses-hil-for-virtual-commissioning-of-offshore-machines.html

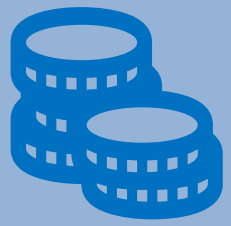

Operations
Reduced operating costs
Reduced risks
Test software without operation disruption


Operations
Understand how system behaves
Operator training
Reproduce issues from field data
What-if scenarios
Capitalization


Operations
Development
Early system integration
Fault injection without damage
Easier analysis and debug
Automated and repeatable tests…
… before prototypes are available !
Capitalization



Short **agile** iteration cycles

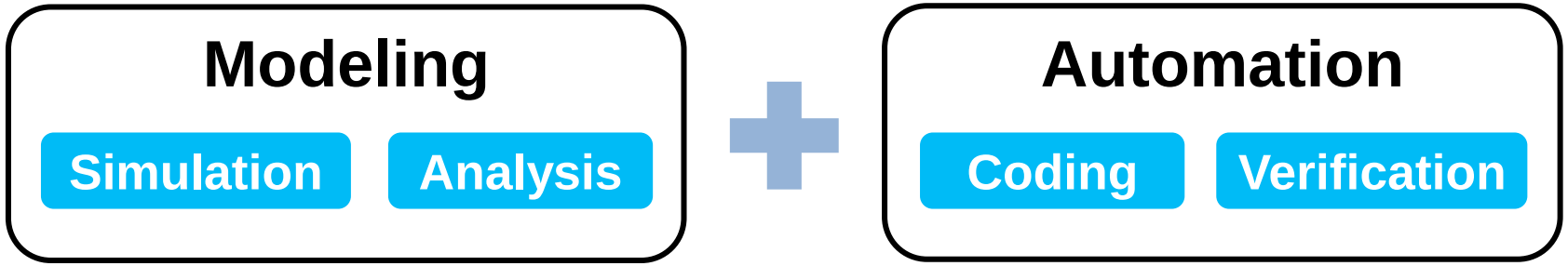


Saved time and cost

Minimal defects and **high quality**

Model-Based Design

Systematic use of **models** throughout the development process

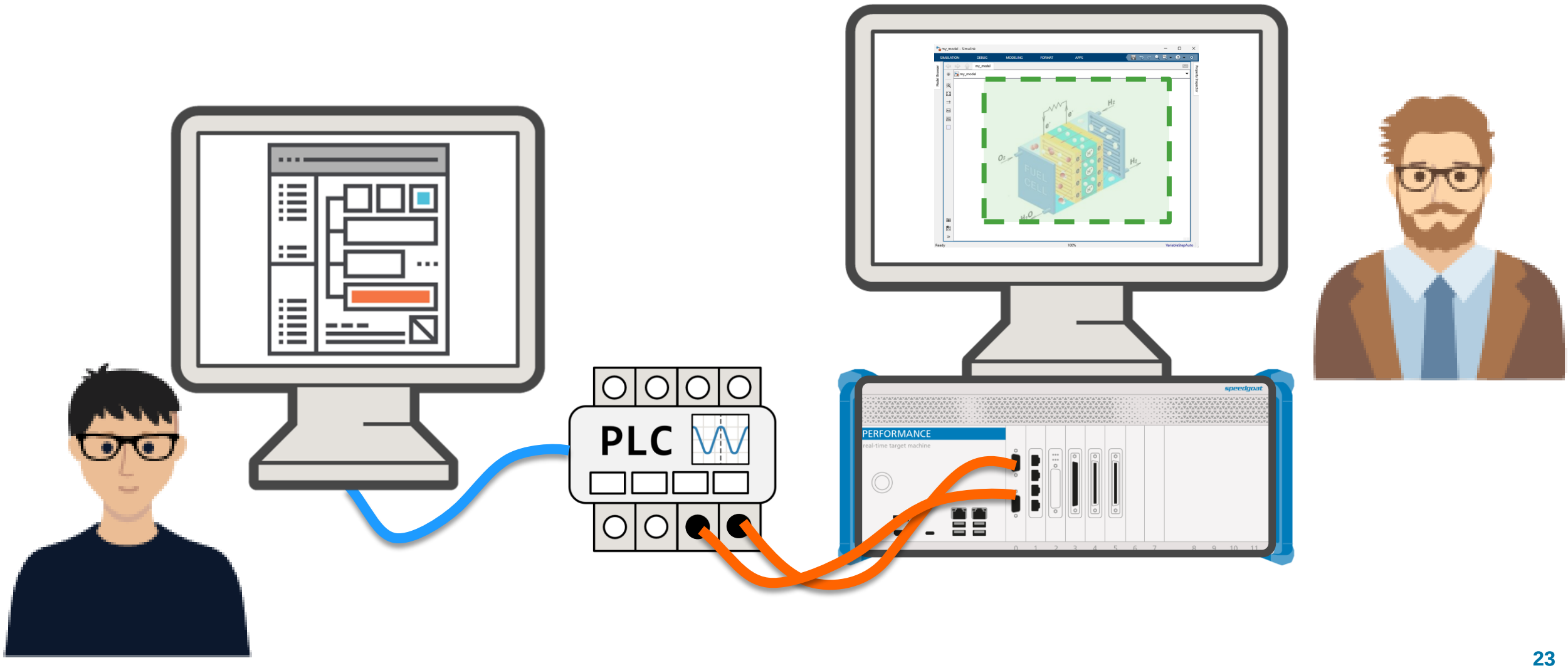


Short **agile** iteration cycles

Saved time and cost

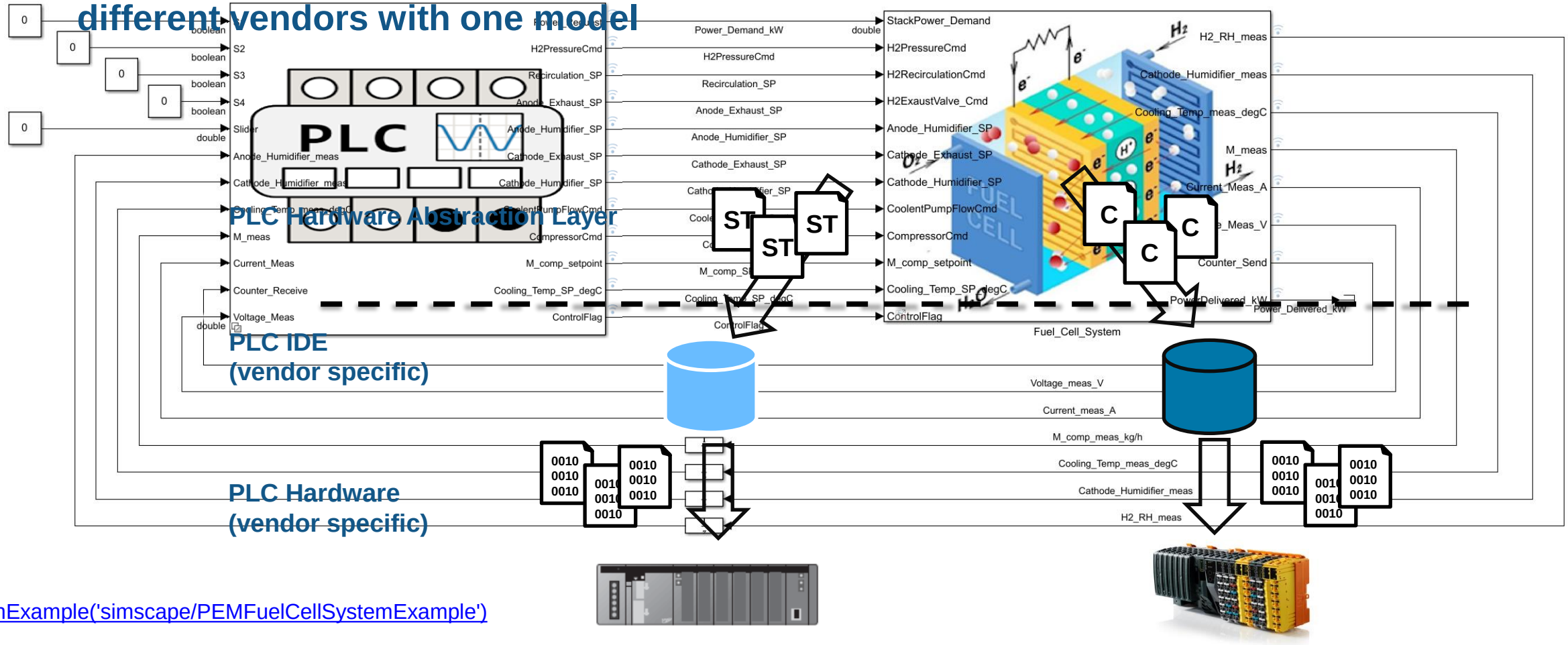
Minimal defects and **high quality**

- ☑ Modeling and desktop simulation
- ☑ Code generation for PLC platforms
- ☑ Hardware in the loop


PLC
PERFORMANCE
real-time target machine
speedgoat

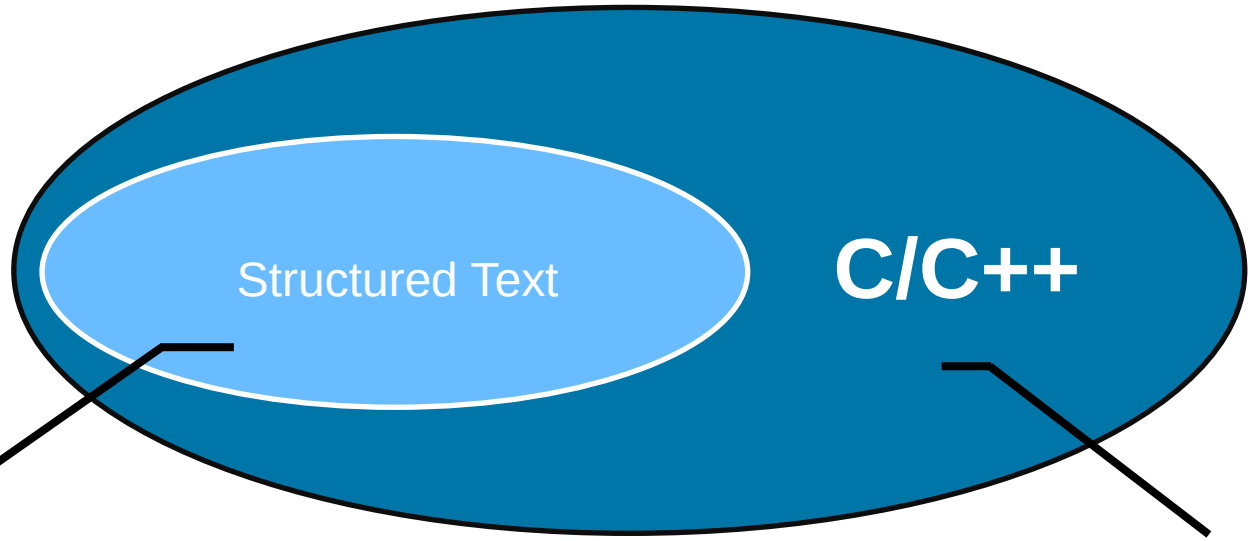
Generate C/C++ or IEC 61131-3

Targeting multiple PLCs from different vendors with one model



openExample('simscape/PEMFuelCellSystemExample')

Generate C/C++ or IEC 61131-3



MATLAB/Simulink semantics supported

- Discrete time only
- Simulink blocks
- Stateflow charts
- MATLAB code

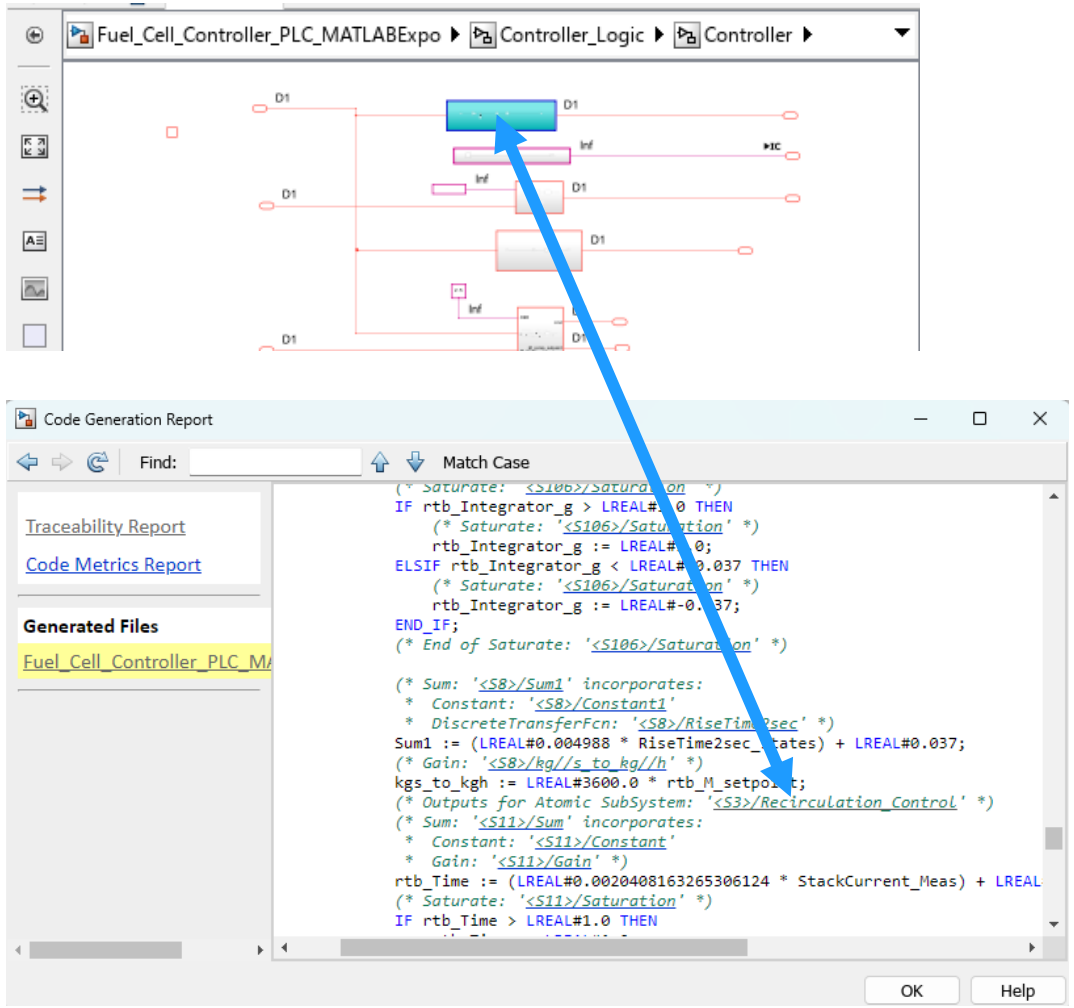
PLC Code Generation
Generate Structured Text code using Simulink® PLC Coder™.

- Discrete & Continuous time
- More Simulink blocks
- More Stateflow semantics
- More MATLAB code
- More scheduling patterns

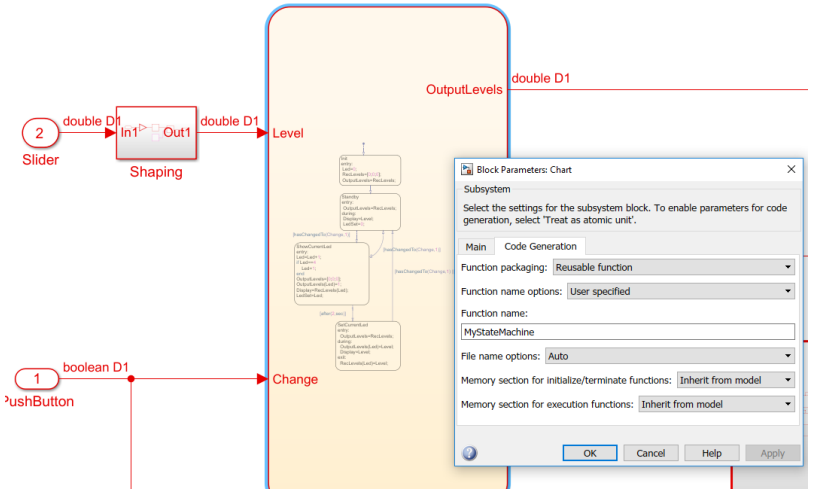
C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

C/C++ & IEC 61131-3
Shared core functionalities

Traceability



Code optimization

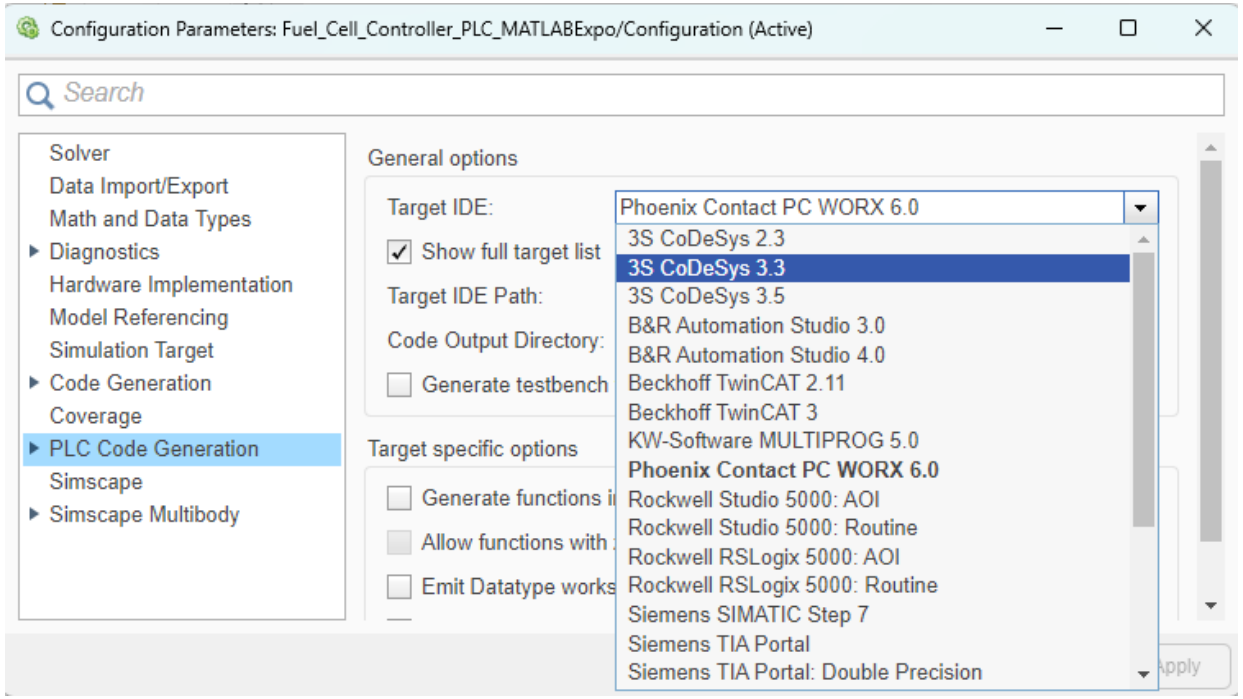


Like

- Dead-code elimination
- Expression folding
- For-loop fusion
- Inline vs tunable parameters
- Signal storage reuse
- Subsystem reuse (shown)
- …

Generate Structured Text

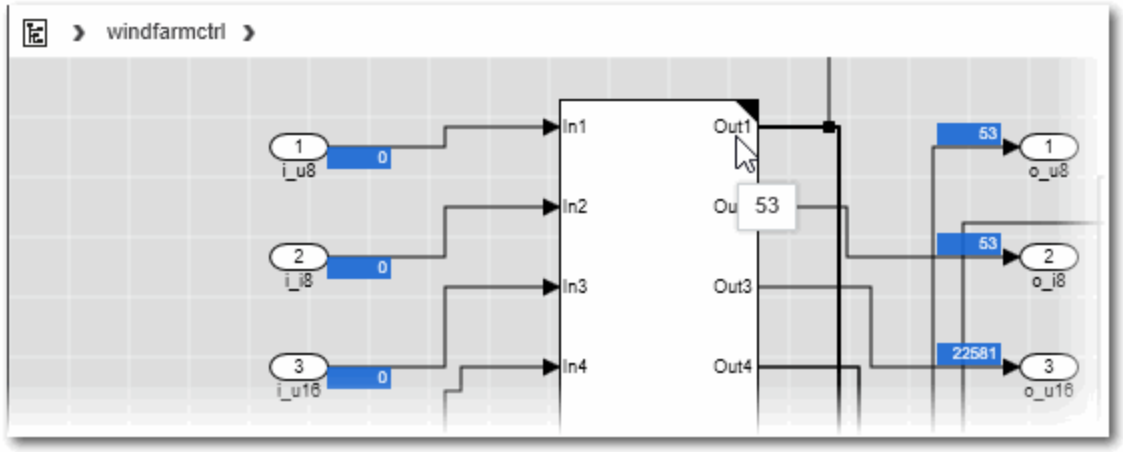
- Generate IEC 61131-3 Structured Text from
  - Simulink models
  - Stateflow charts
  - MATLAB code
- Generate Structured Text for
  - Rockwell Automation Studio 5000
  - Siemens STEP 7/TIA Portal
  - 3S CODESYS
  - Many other IDEs and PLCs



Generate C/C++ code

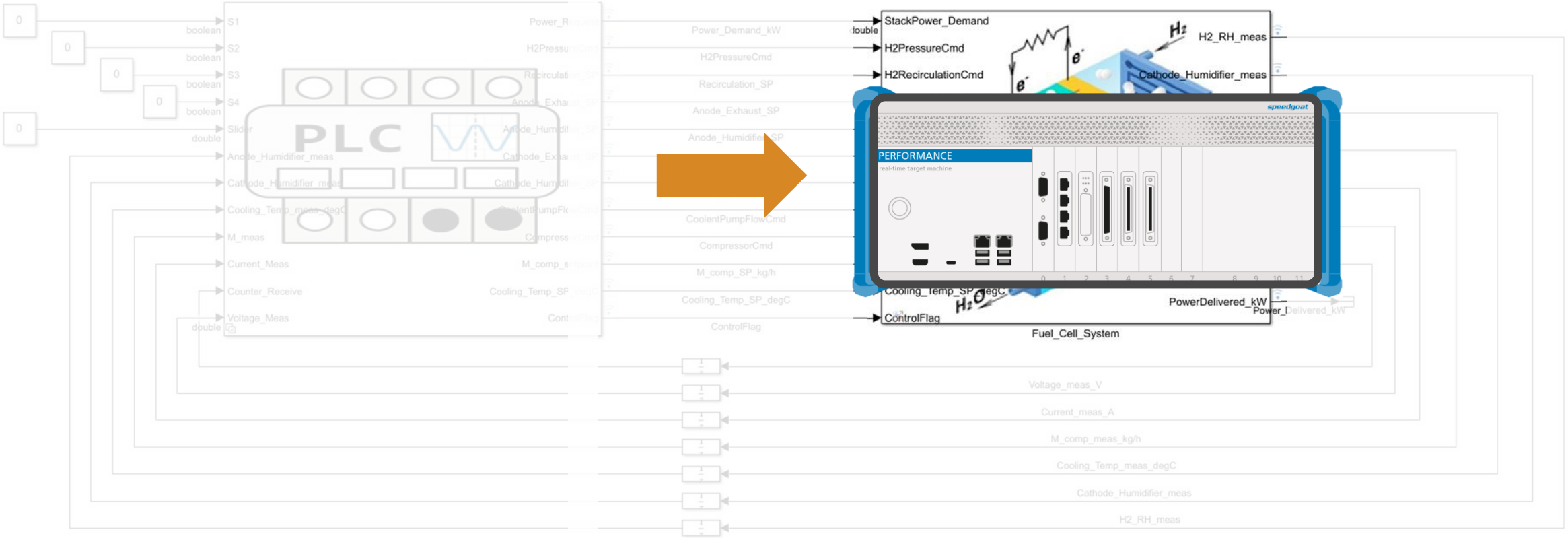
- Targets are developed & supported by PLC manufacturers like
  - B&R Industrial Automation
  - Beckhoff Automation
  - Phoenix Contact
  - Many others in our Partner Program

- Better integration / debugging capability / advanced features
  - Model viewer
  - Variable subscription from Simulink
  - External Mode
  - PLC automation from MATLAB scripts
  - …

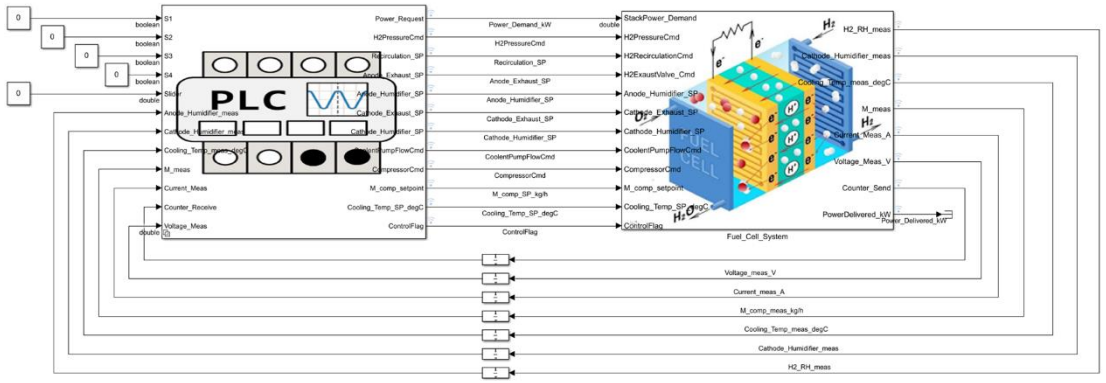


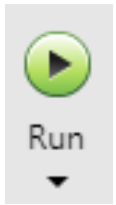
Integrate automatically generated code into the PLC software through the vendor's IDE

Hardware-In-the-Loop



From Desktop Simulation to Real-Time





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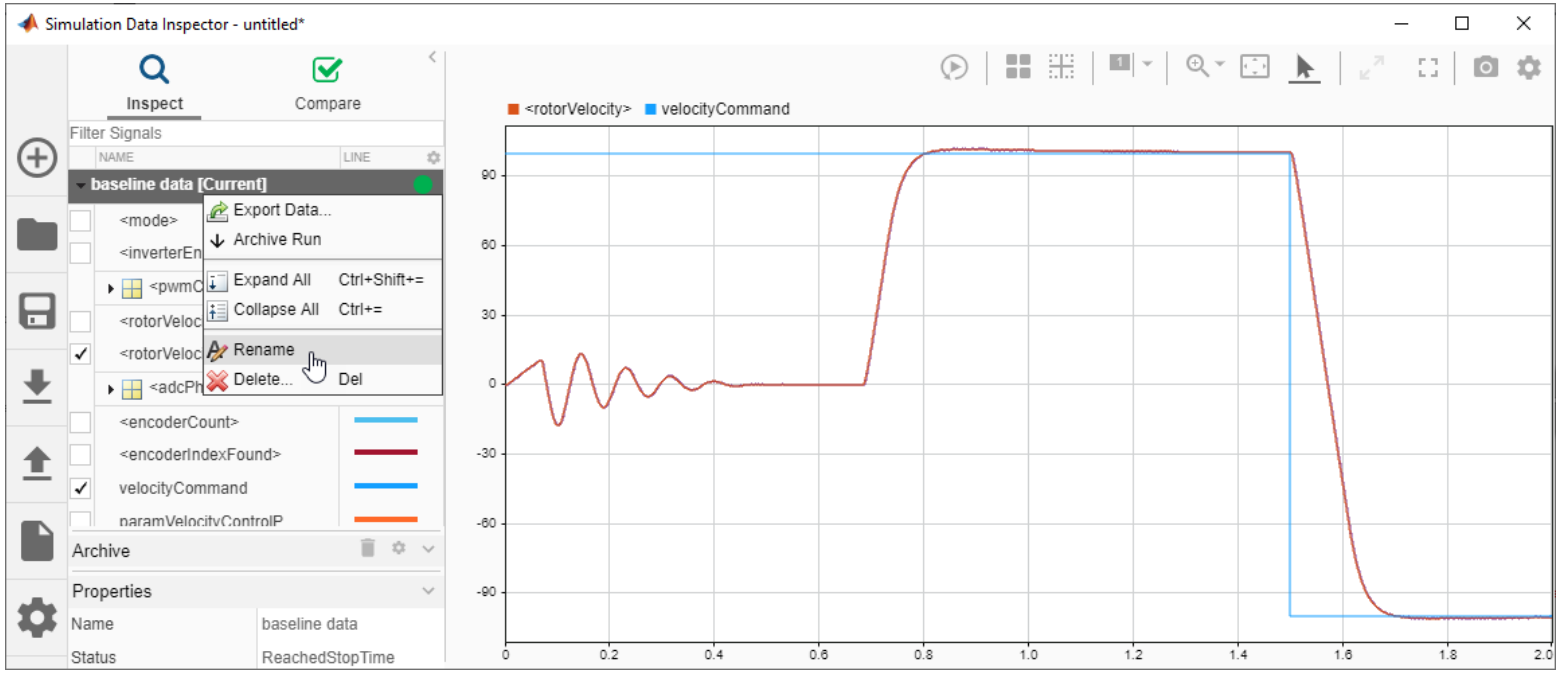
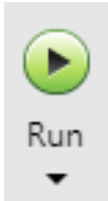


From Desktop Simulation to Real-Time



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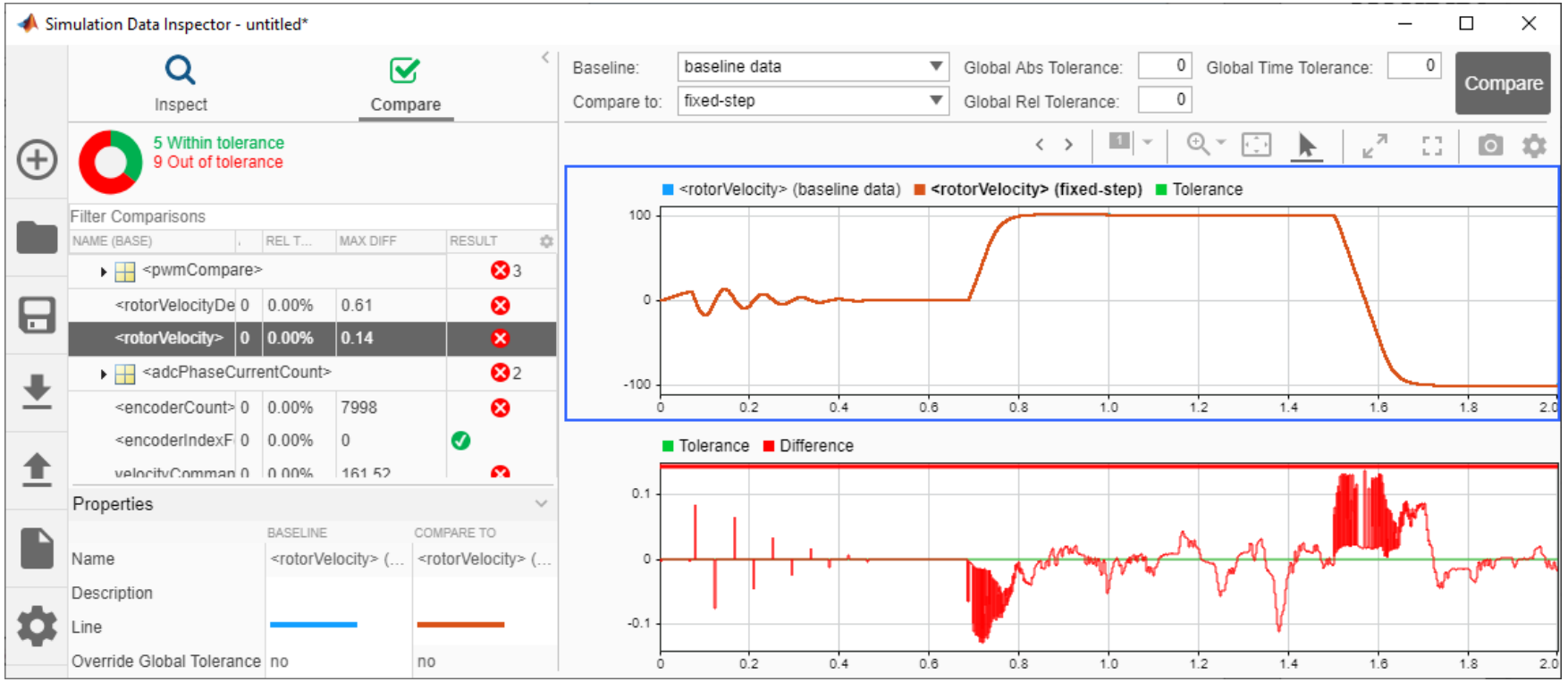
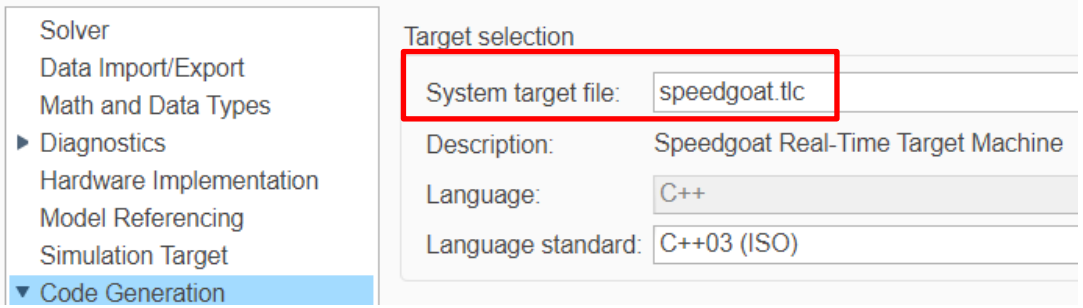
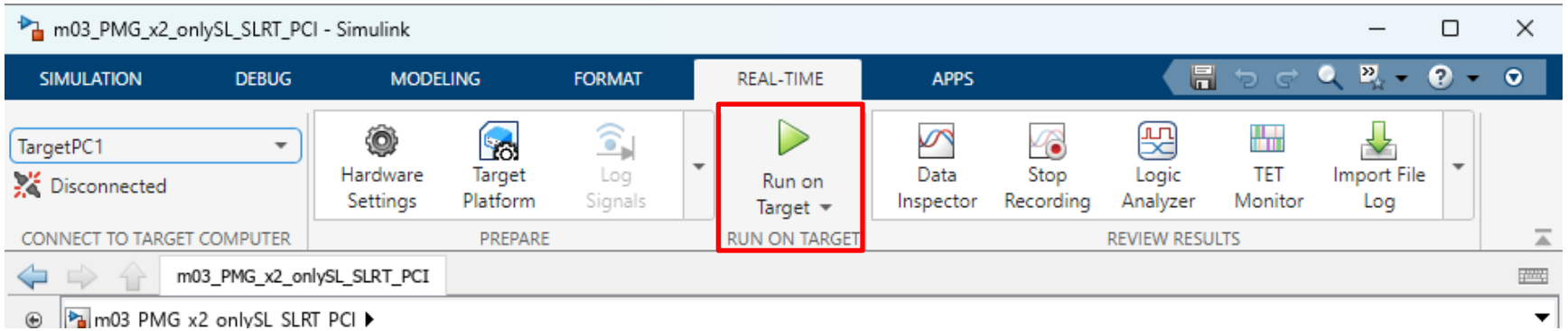
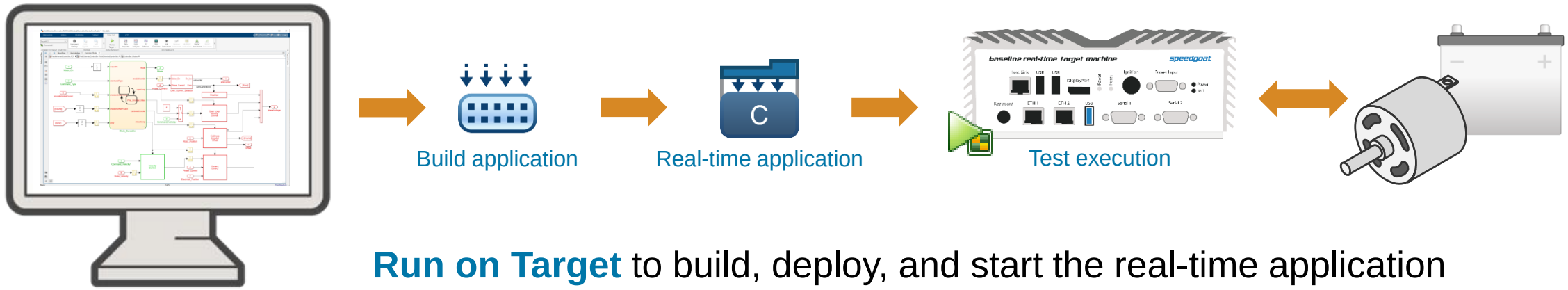


From Desktop Simulation to Real-Time



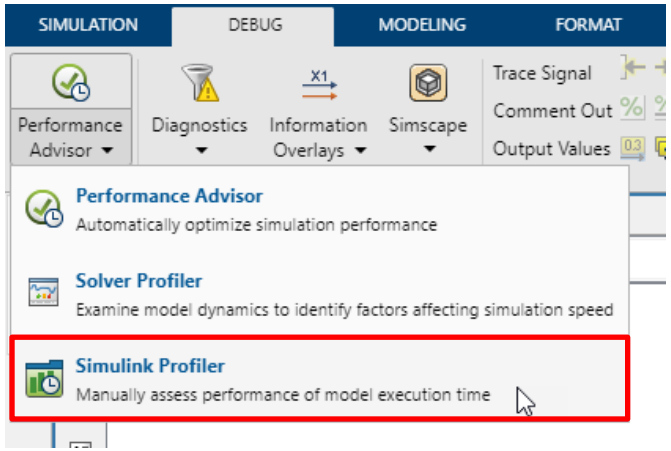




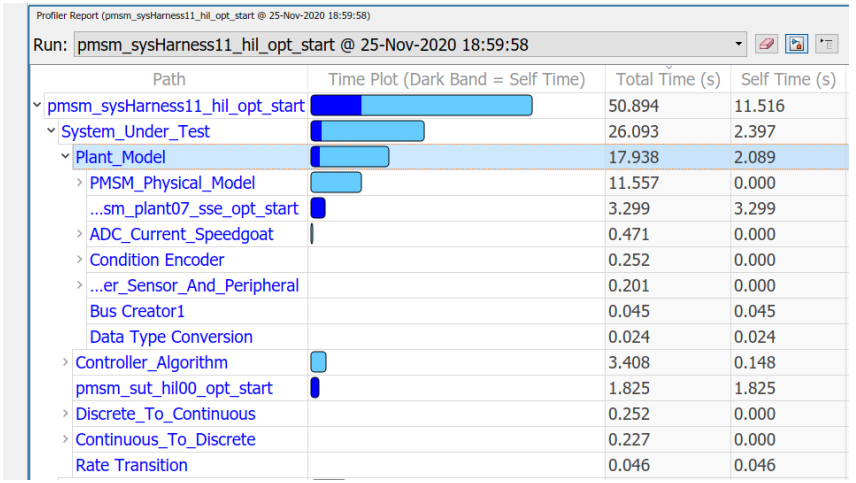
Run on Target to build, deploy, and start the real-time application

From Desktop Simulation to Real-Time

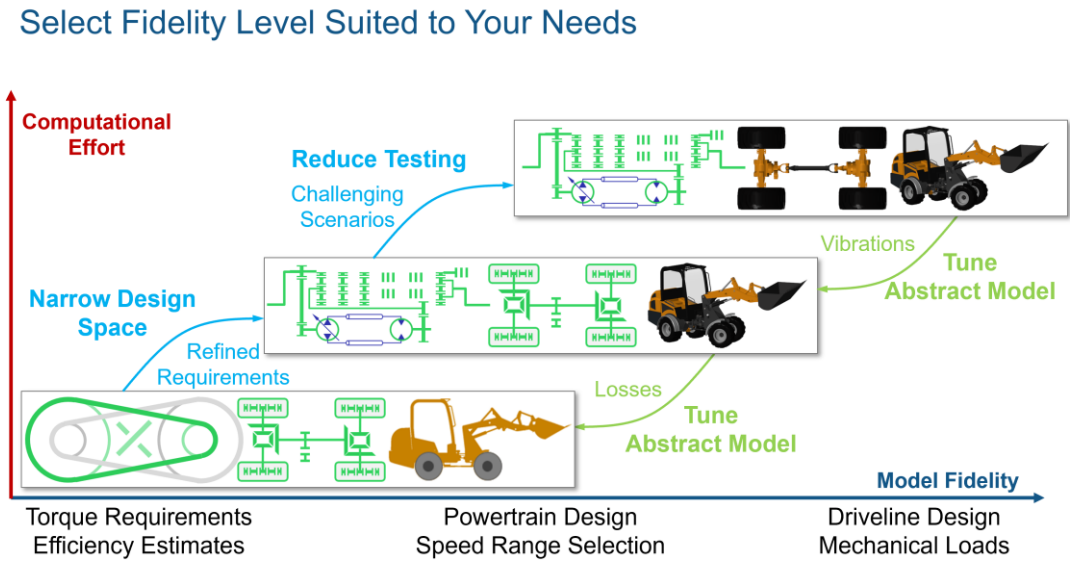
```
Simulink Real-Time: R2022a (22.1.0)
Network (IP Address/Netmask): 10.10.10.153 / 255.255.255.0
Speedgoat Baseline real-time target machine SN i58
Speedgoat I/O Blockset v9.3.0 build 23675
State: TARGET ERROR -> pmsm_sysHarness11_hil_opt_start (MODEL ERROR)
Execution Time (Current/Stop): 0.0s / 2.0s
Disk Usage: 5.5% used of 45.3 GB
Overruns (Current/Max): 6/0, 0/0, 0/0
Task Execution Time (Rate: Current/Max)
TET_8.000e-05: 5.470e-04s / 5.470e-04s TET_8.000e-03: -1.000e+00s / -1.000e+00s
TET_2.000e-03: -1.000e+00s / -1.000e+00s
--LOG-------------------------------------------------------------------------------
03:09:17.023543 [info    ] Starting model dut_closed_loop
03:09:17.231542 [info    ] SG: PWM module(s) 0x1 start
03:11:14.367000 [info    ] TET 0 avg: 1.3243e-05 min: 1.23e-05    max: 4.5588e-05
03:11:14.368001 [info    ] SG: PWM module(s) 0x0 end
03:11:14.368001 [info    ] Stopping model dut_closed_loop at 117.026s
04:00:07.293272 [info    ] Loading model pmsm_sysHarness11_hil_opt_start
04:00:07.509271 [info    ] Ready to start
04:00:24.891201 [info    ] Starting model pmsm_sysHarness11_hil_opt_start in time polling mode
04:00:24.891201 [info    ] PTP clock synchronization does not work in polling mode
04:00:24.897201 [fatal   ] Overload limit (0) exceeded in 8e-05s (tid=0) rate with 6 overloads
```

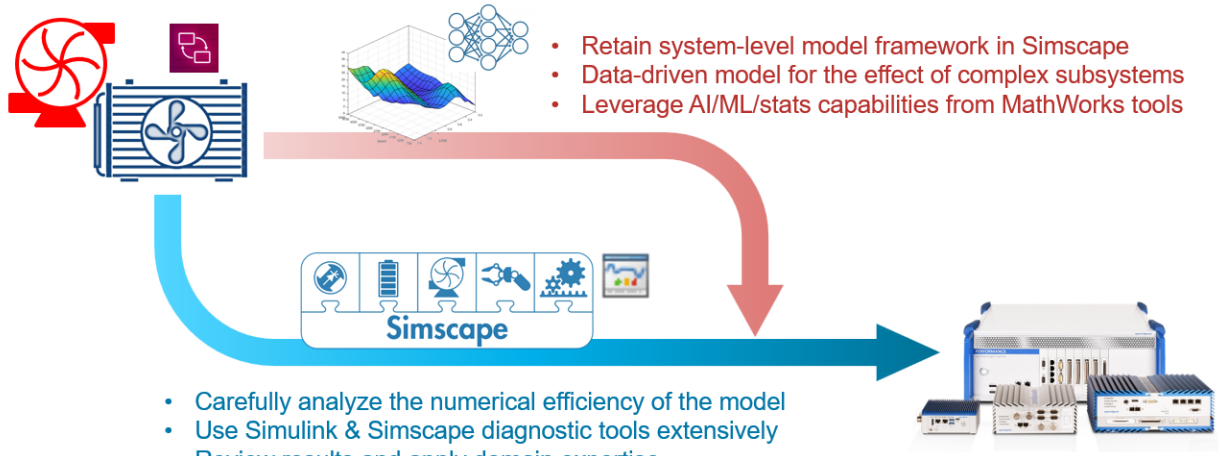



```
>> tg.ModelStatus.TETInfo(1)

ans =

  struct with fields:

          Rate: 8.0000e-05
        TETMin: 3.3029e-04
        TETMax: 5.1772e-04
        TETAvg: 3.8792e-04
    TETMinTime: 0.0713
    TETMaxTime: 1.4628
```



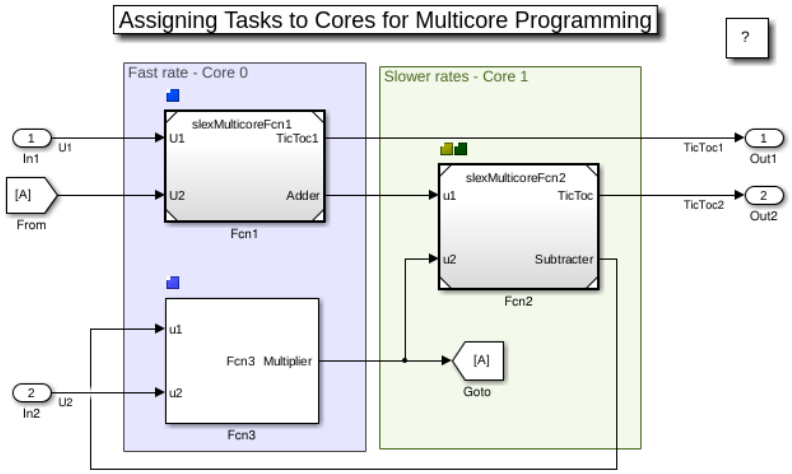
From Desktop Simulation to Real-Time





- Retain system-level model framework in Simscape
- Data-driven model for the effect of complex subsystems
- Leverage AI/ML/stats capabilities from MathWorks tools

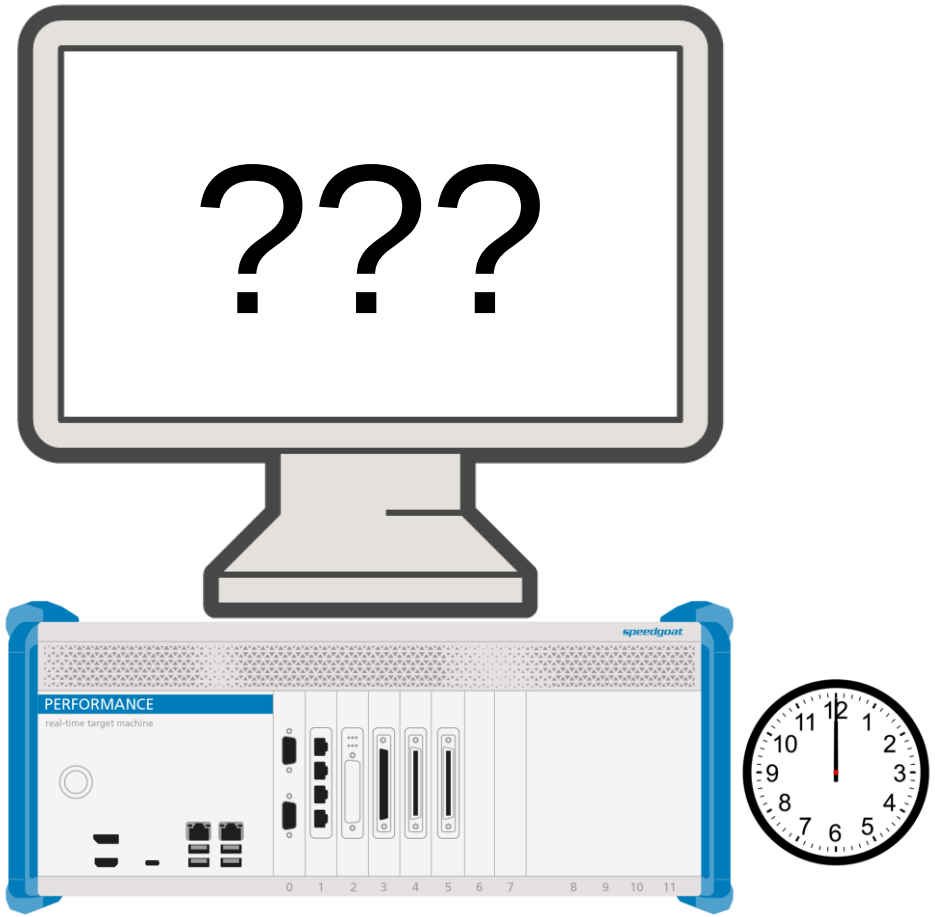
- Carefully analyze the numerical efficiency of the model
- Use Simulink & Simscape diagnostic tools extensively
- Review results and apply domain expertise
- Adjust components & parameters when needed



HDL Code for FPGA

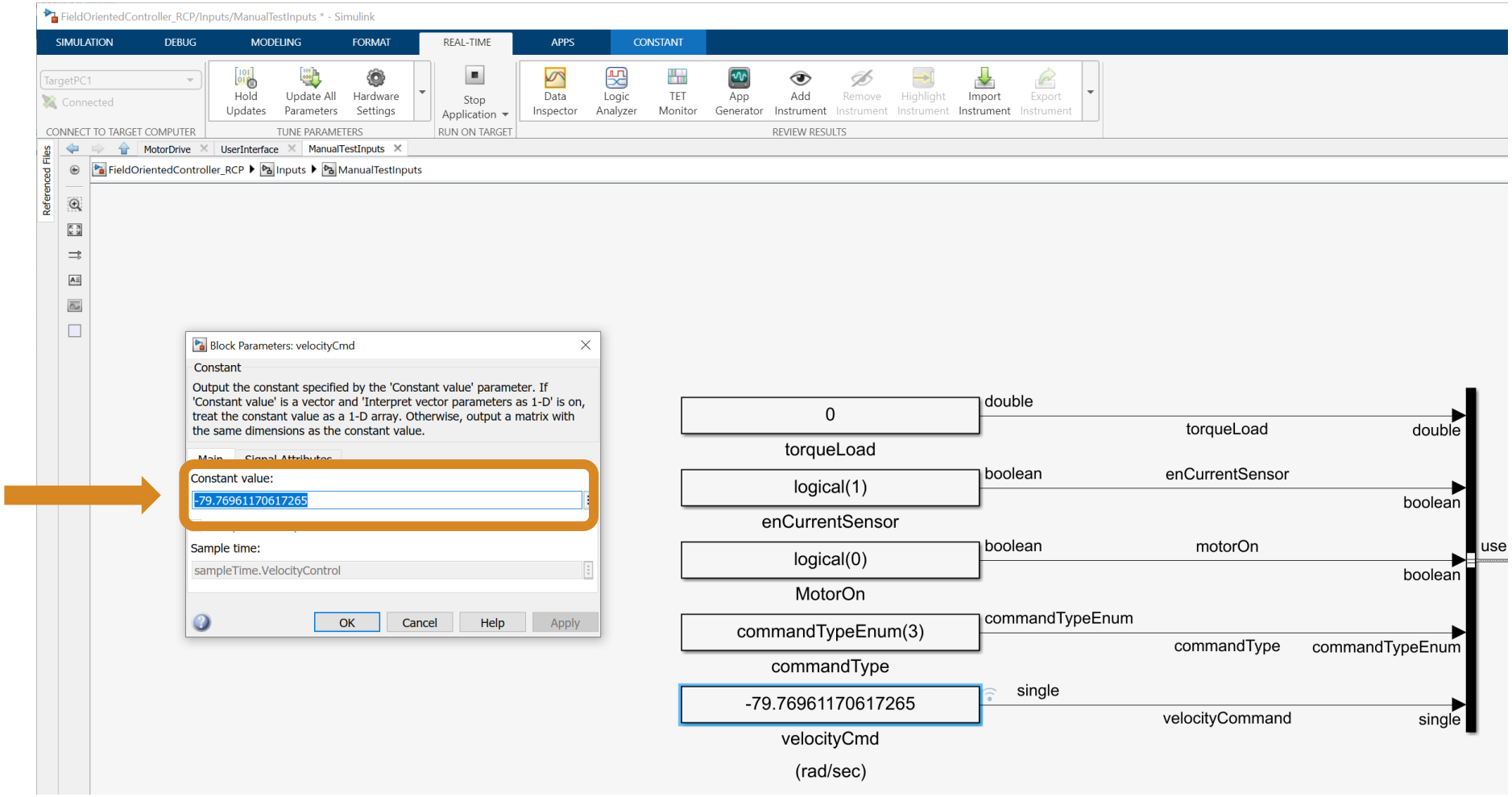
■ ■ ■

Debug real-time algorithms

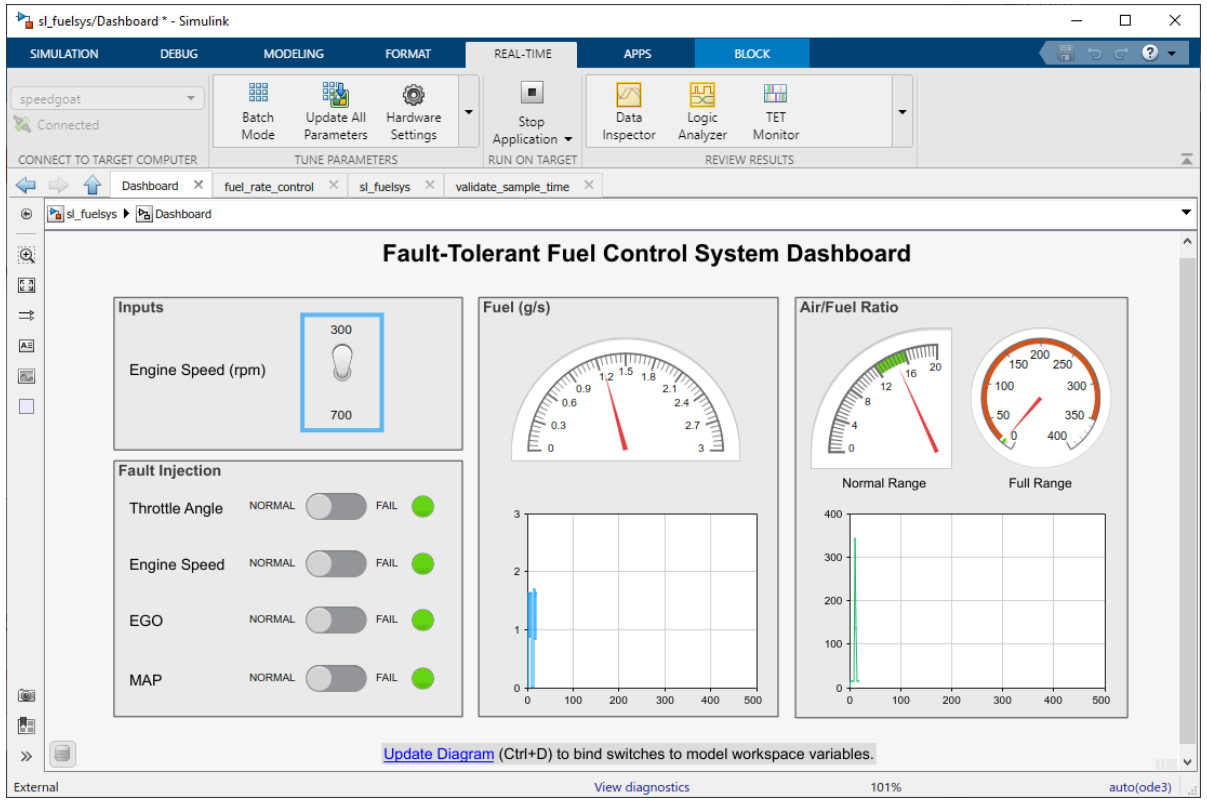


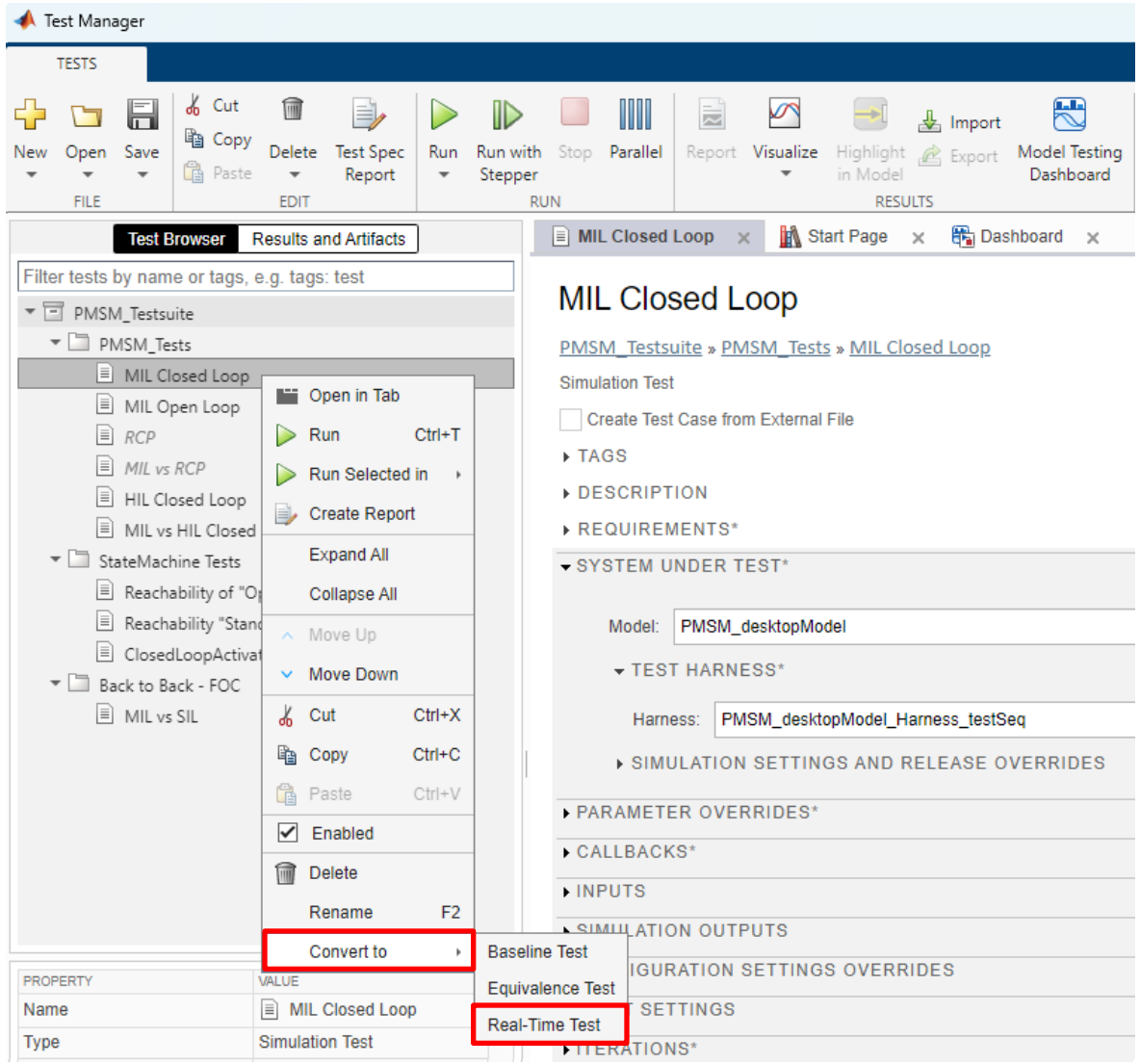
Debug real-time algorithms directly from Simulink

Tune parameters from the Simulink interface

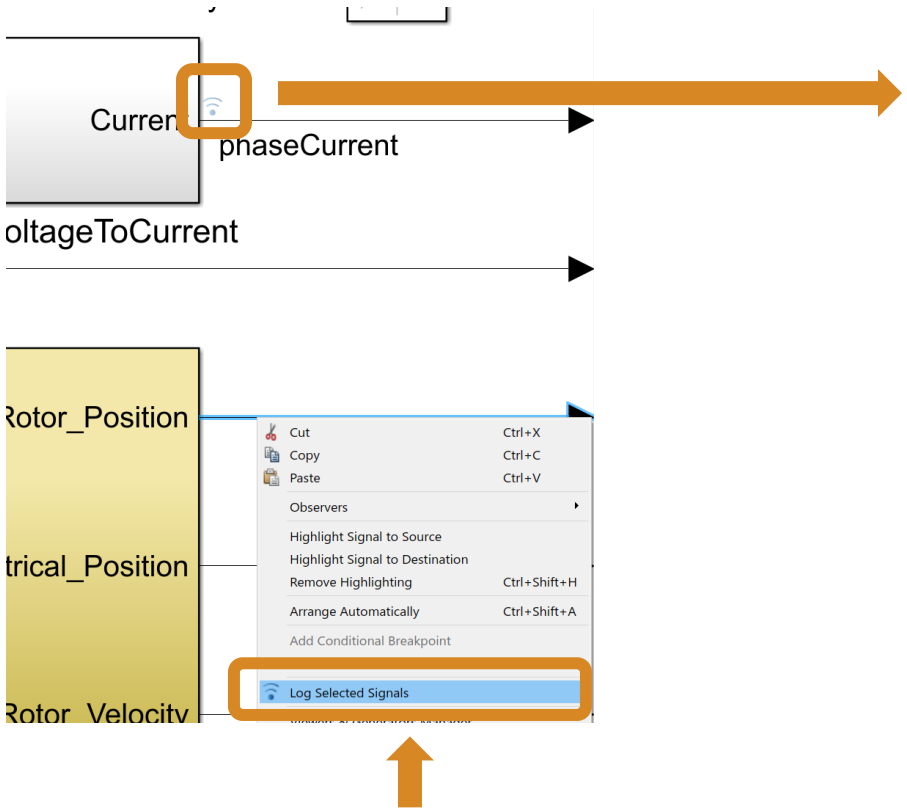


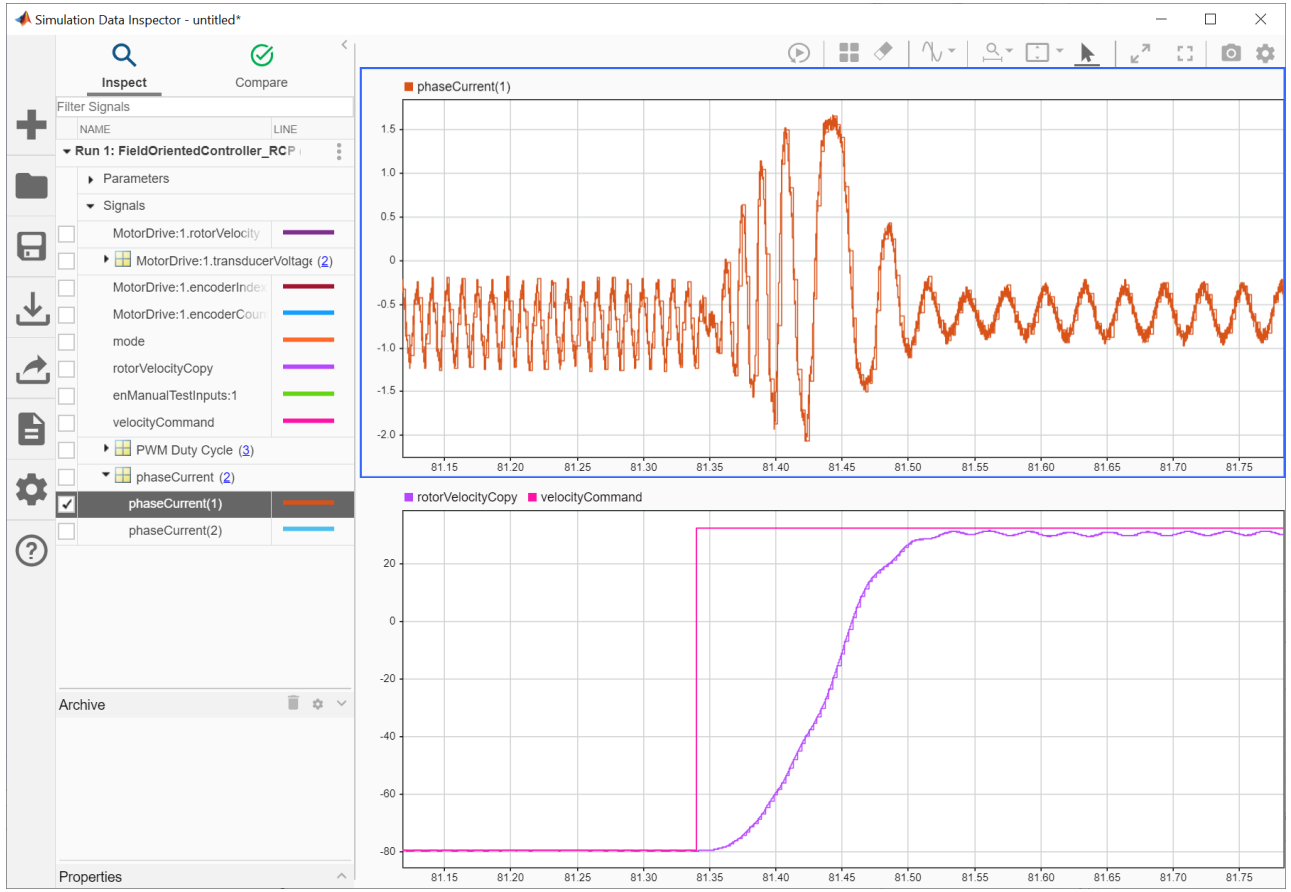
Debug real-time algorithms directly from Simulink





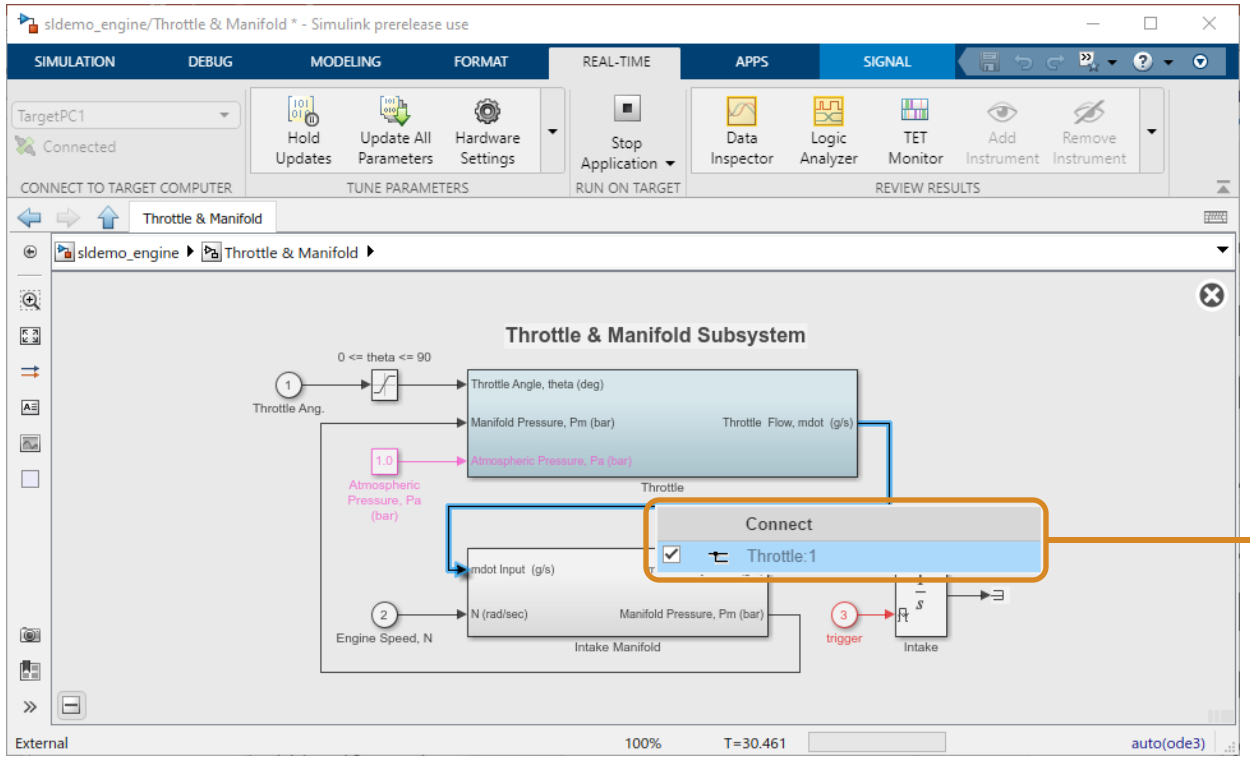
Debug real-time algorithms directly from Simulink

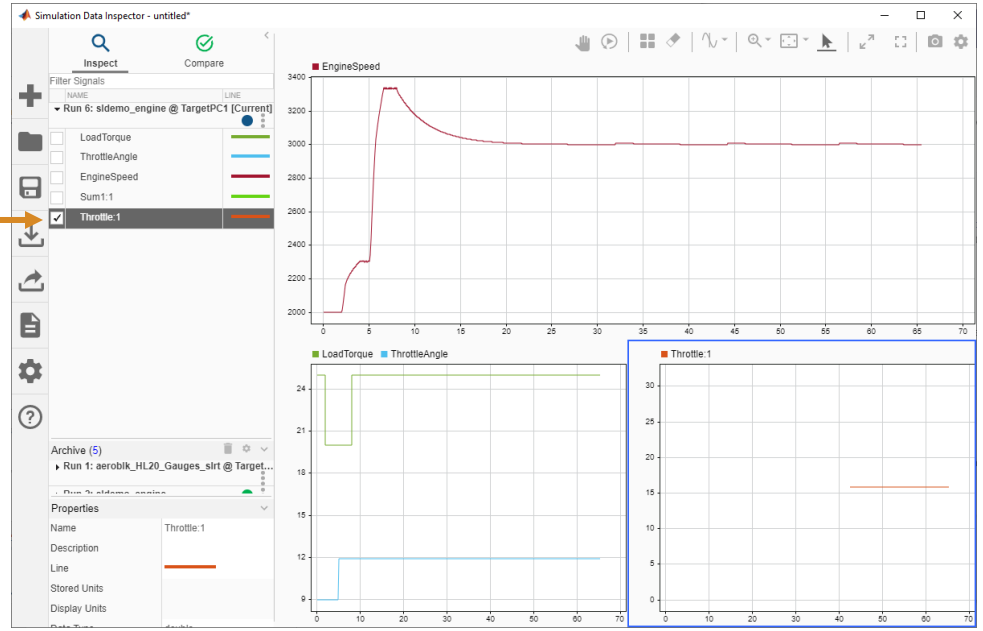


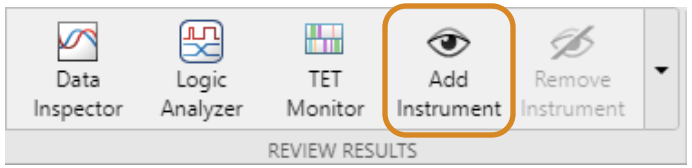


Select signals to log/view in Simulation Data Inspector

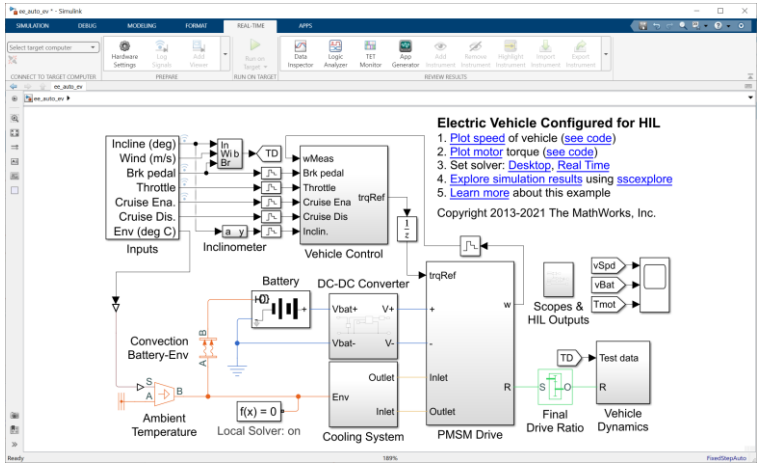
Debug real-time algorithms directly from Simulink



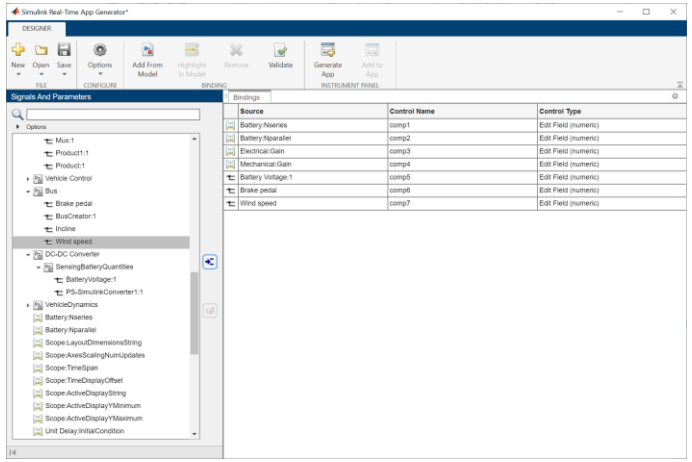




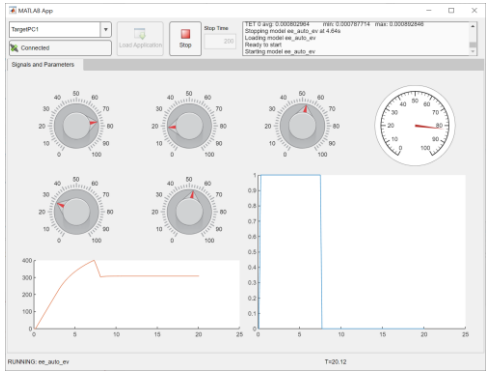
Debug real-time algorithms with dedicated application



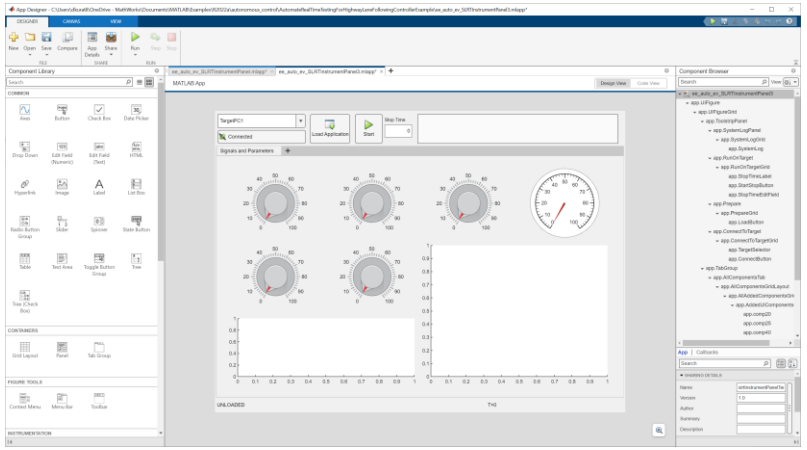
1. Start from Simulink



2. Select signals and parameters



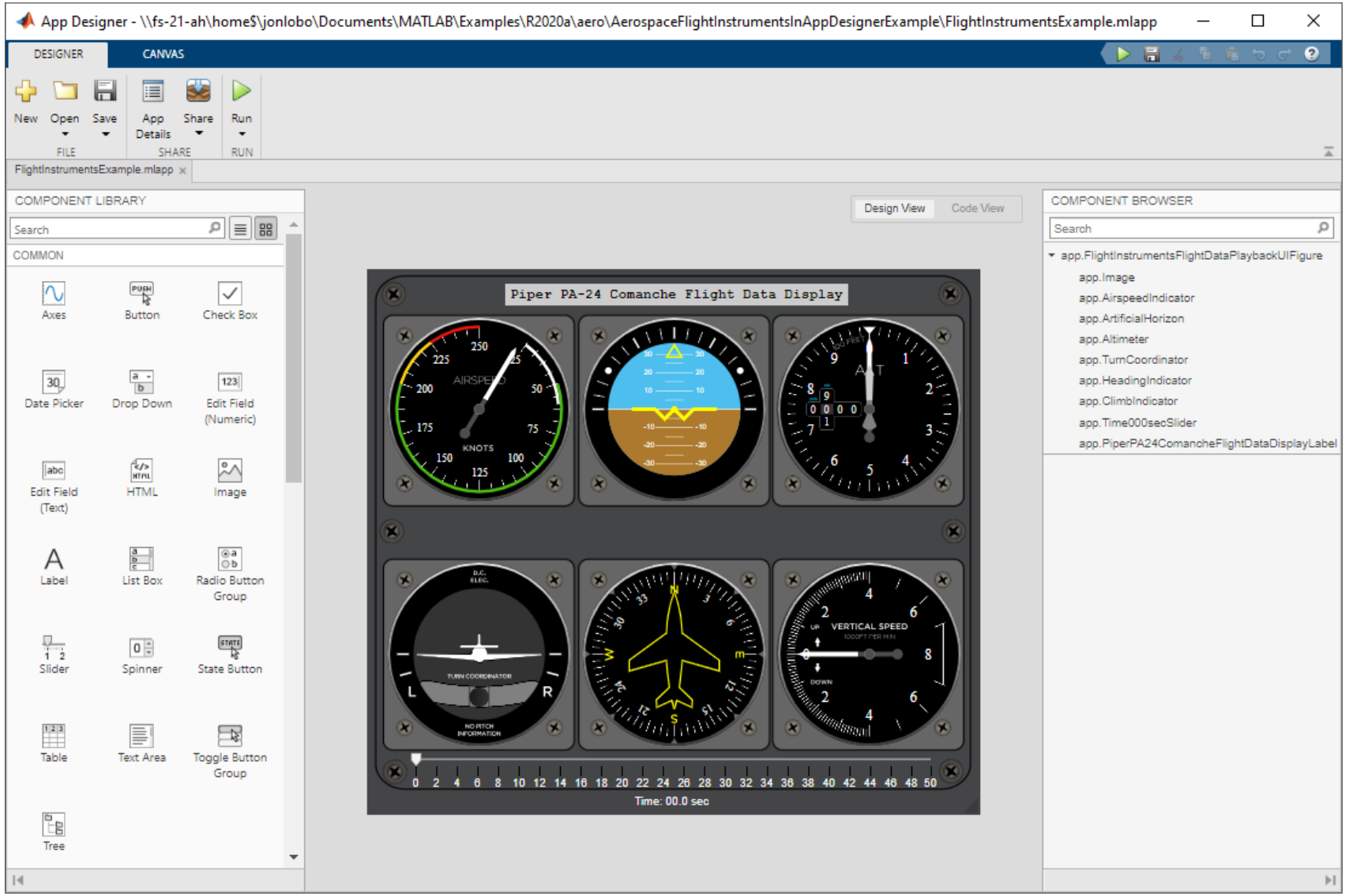
3. Control the target computer



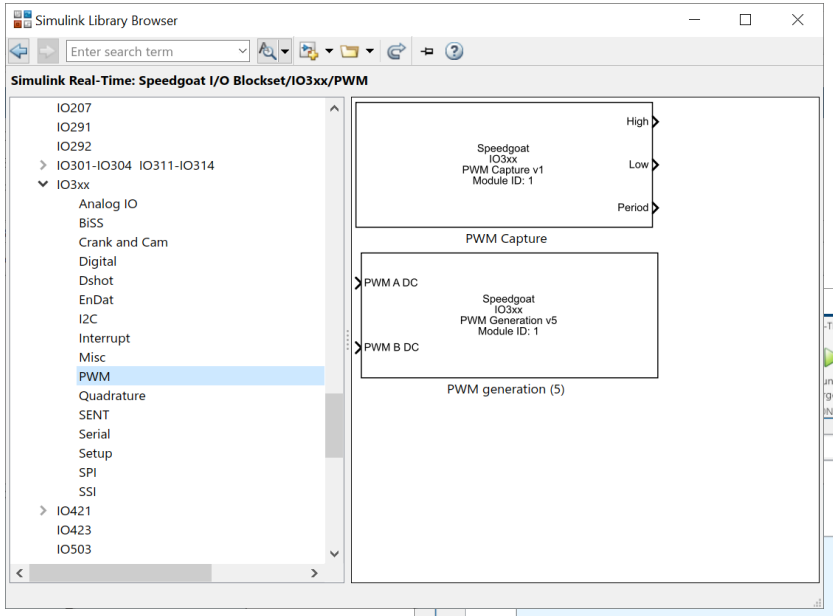
3. Customize the layout in App Designer

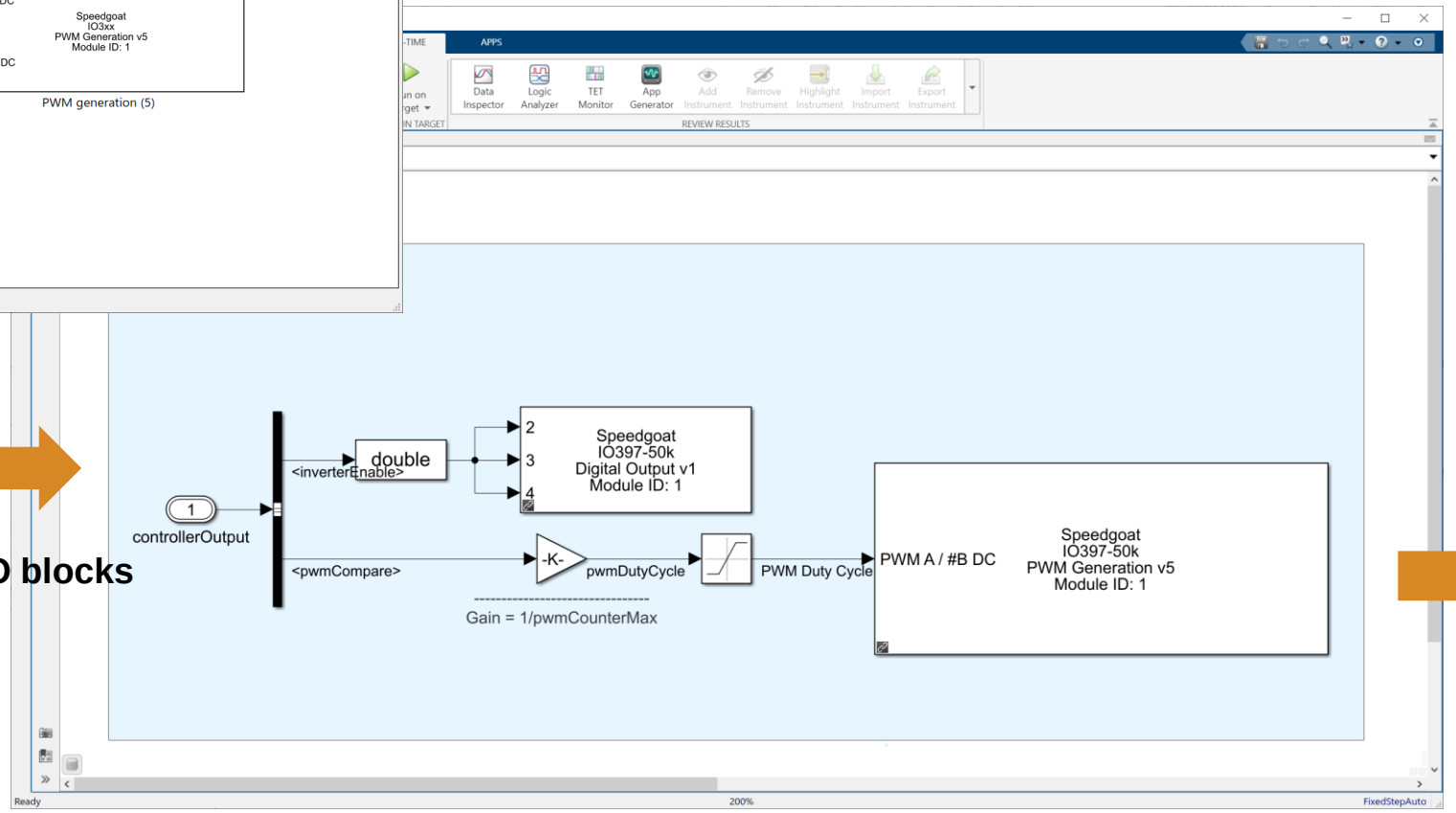
Instrument panels created with App Generator can be customized in App Designer

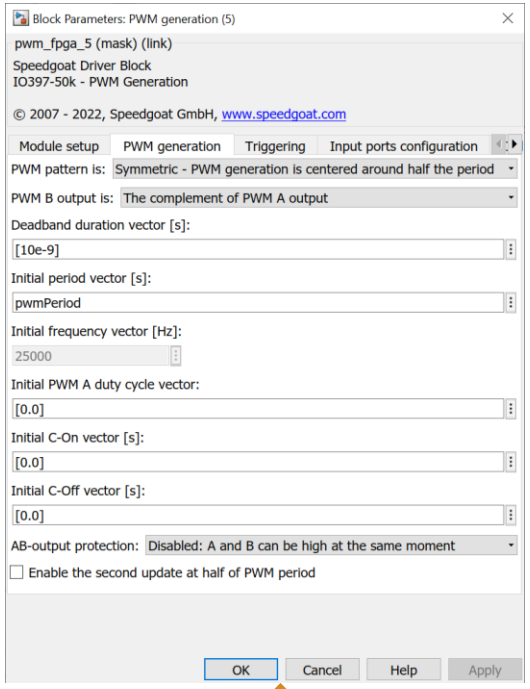
Debug real-time algorithms with dedicated application



Connect the virtual machine to the PLC over an industrial fieldbus



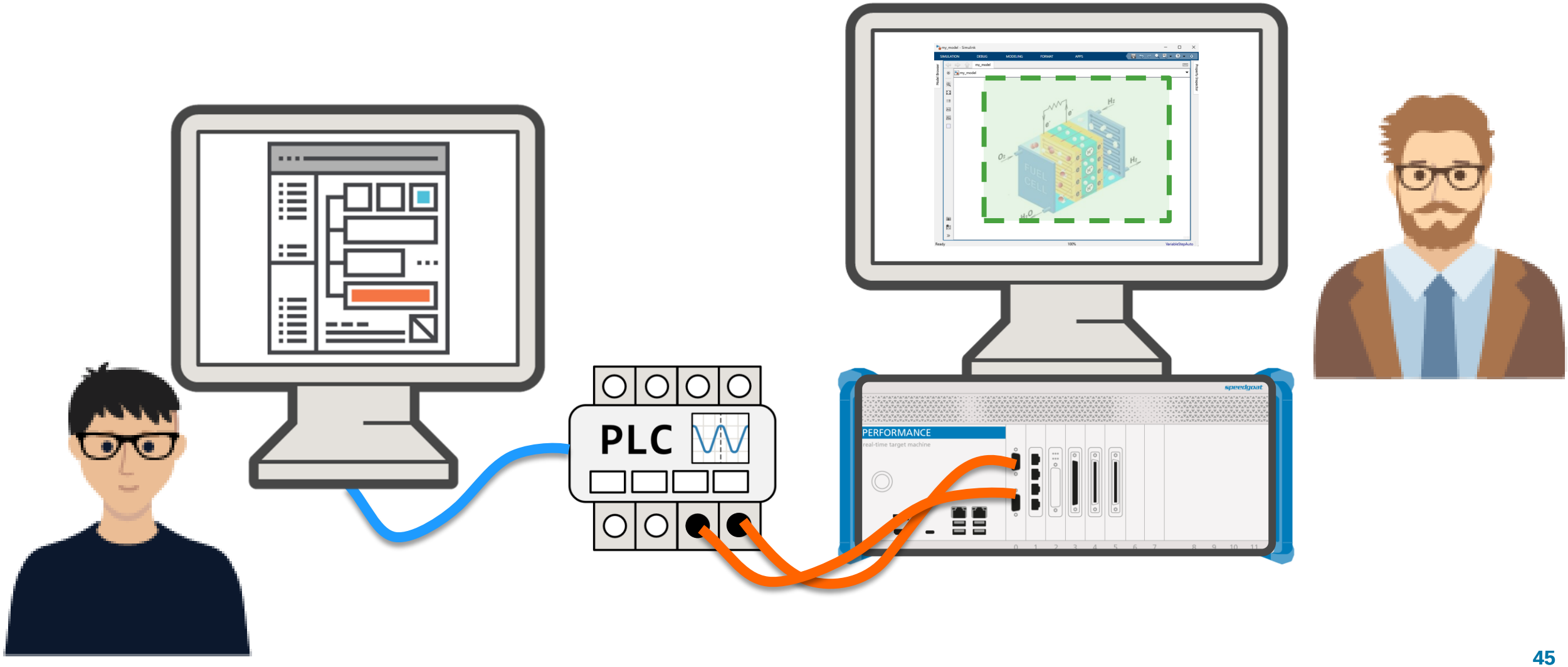




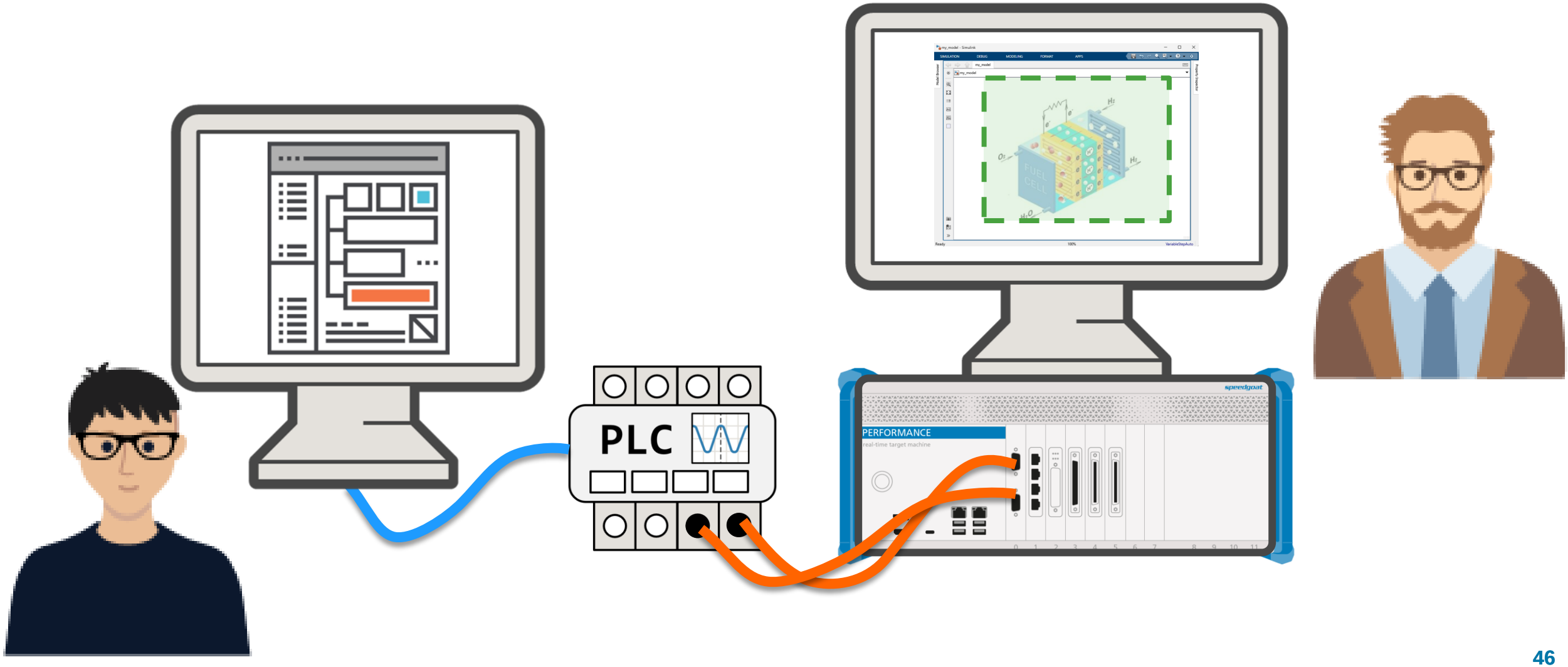
Drag-and-drop I/O blocks

Configure I/O parameters in Simulink

Connect the virtual machine to the PLC over an industrial fieldbus



Discuss with us at our booth!



Development

- Early system integration
- Fault injection without damage
- Easier analysis and debug
- Automated and repeatable tests…

… before prototypes are available

Operations

- Reduced risks
- Reduced operating costs
- Test software without operation disruption

Capitalization

- Understand how system behaves
- Operator training
- Reproduce issues from field data
- What-if scenarios

8 Core Concepts

Model-Based Design

- Executable Specification
- Model elaboration
- System-level simulation
- What-if analysis
- Continuous test and verification
- Virtual prototyping
- Automation
- Knowledge capture

[Managing Model-Based Desing Free eBook by Roger Aarenstrup]

MATLAB EXPO
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Thank you!

MathWorks