

# MATLAB EXPO

 FRANCE

8 octobre 2024 | Paris

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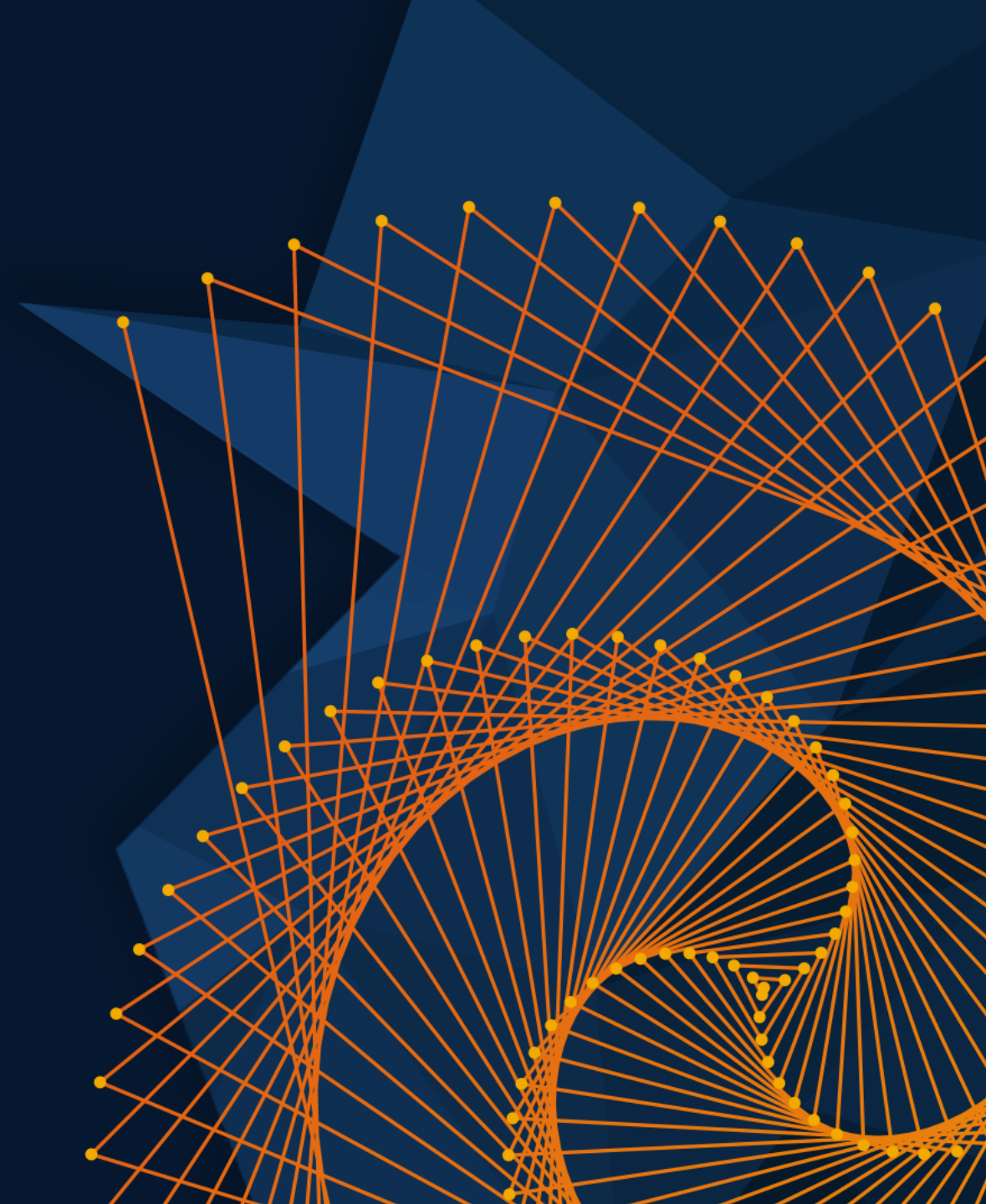
## "Virtual Commissioning" : Accélérez la mise en service de vos systèmes grâce au Jumeau Numérique



Kevin Roblet,  
MathWorks



Morgan Fremovici,  
MathWorks

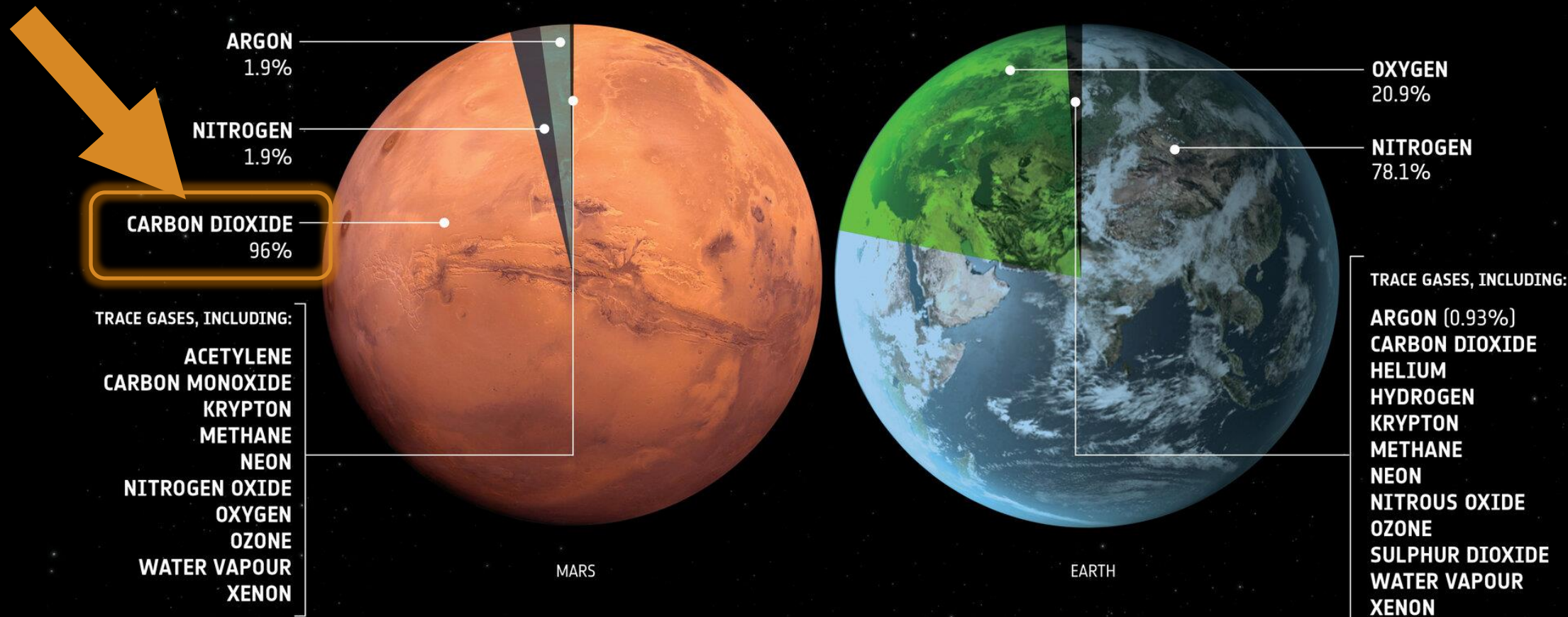


-63°C

225 millions km

CO<sub>2</sub> is the solution...

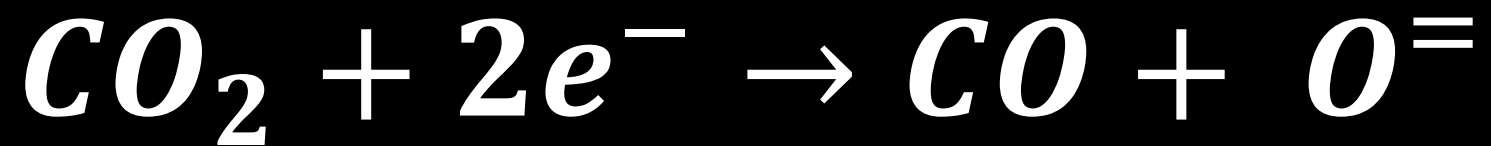
## → COMPARING THE ATMOSPHERES OF MARS AND EARTH



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



# MOXIE

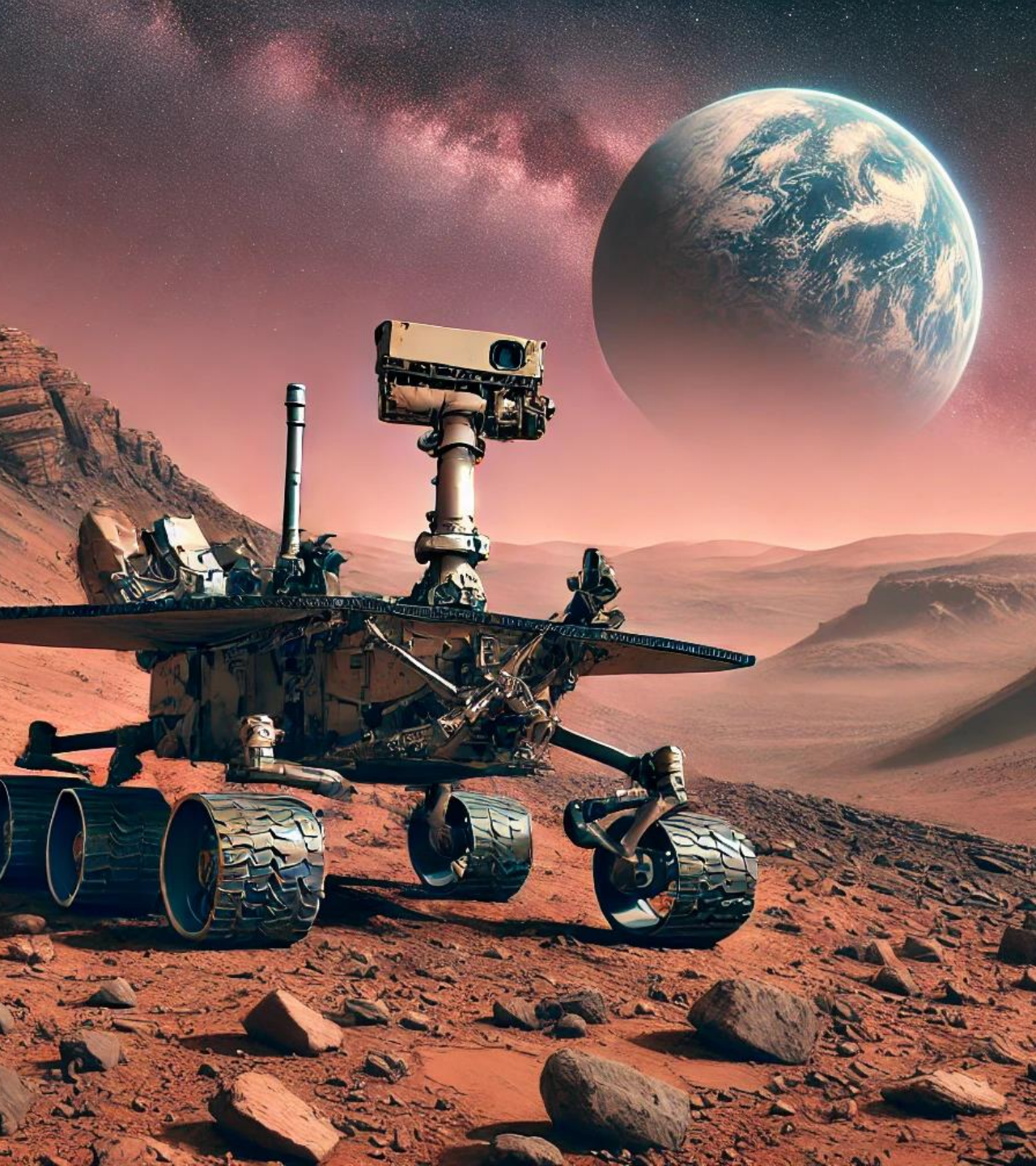






“If we break something on Mars,  
you can’t send anybody to go  
fix it, and you’re done...”



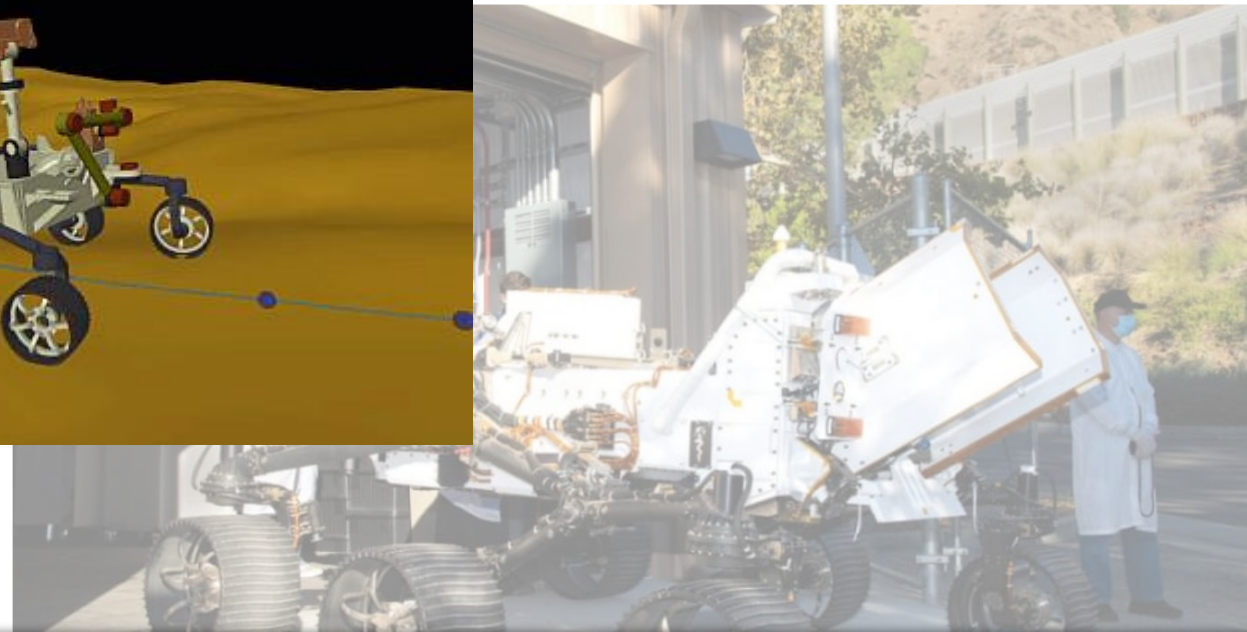
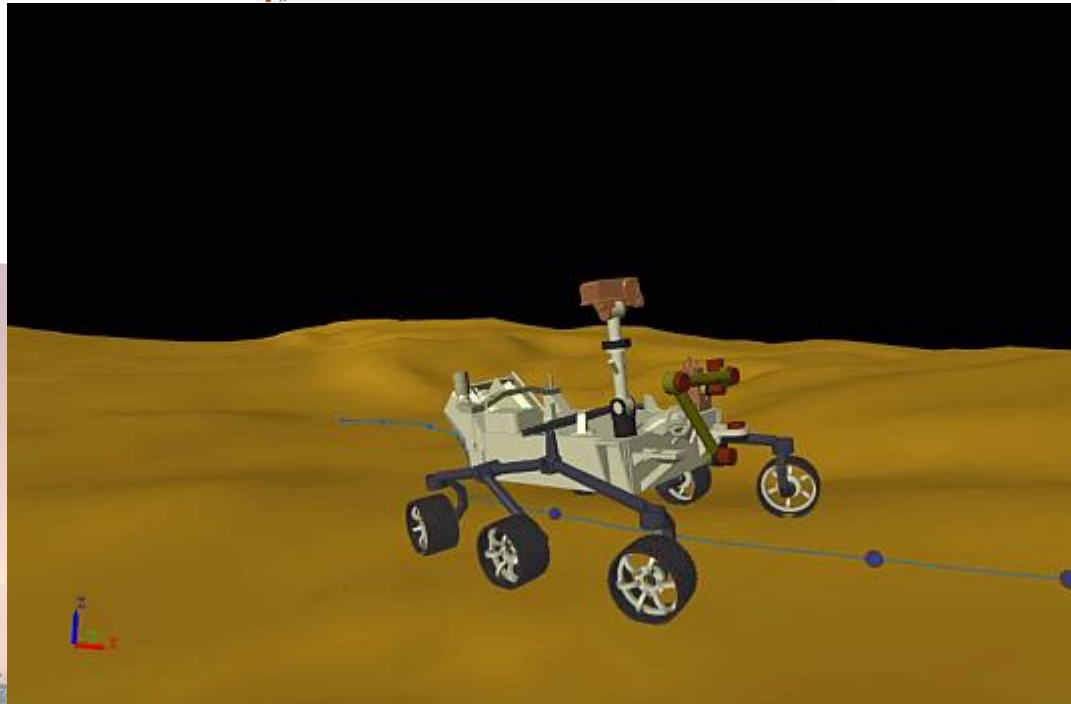
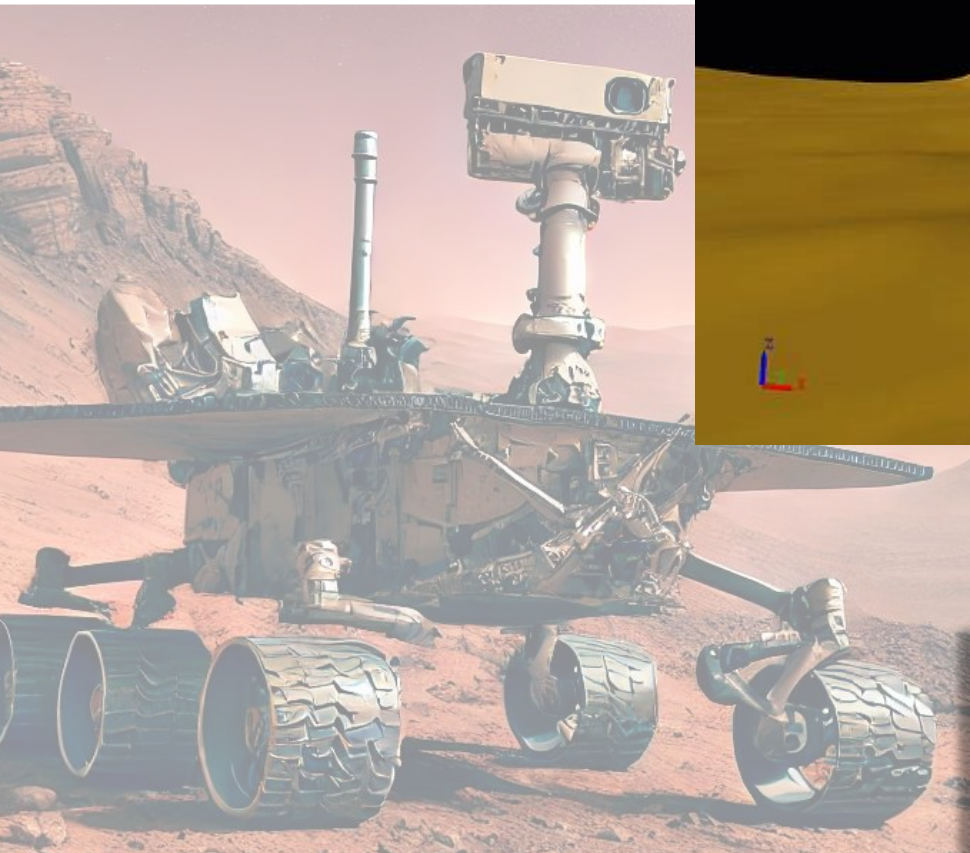


## Early Twin Offers Test Bed for **NASA's Perseverance Mars Rover**



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





"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

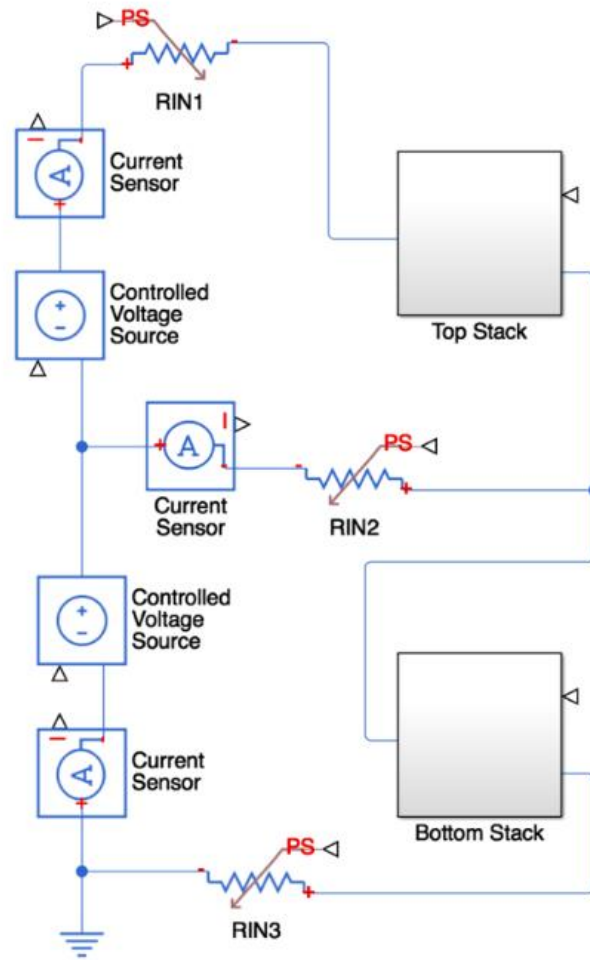
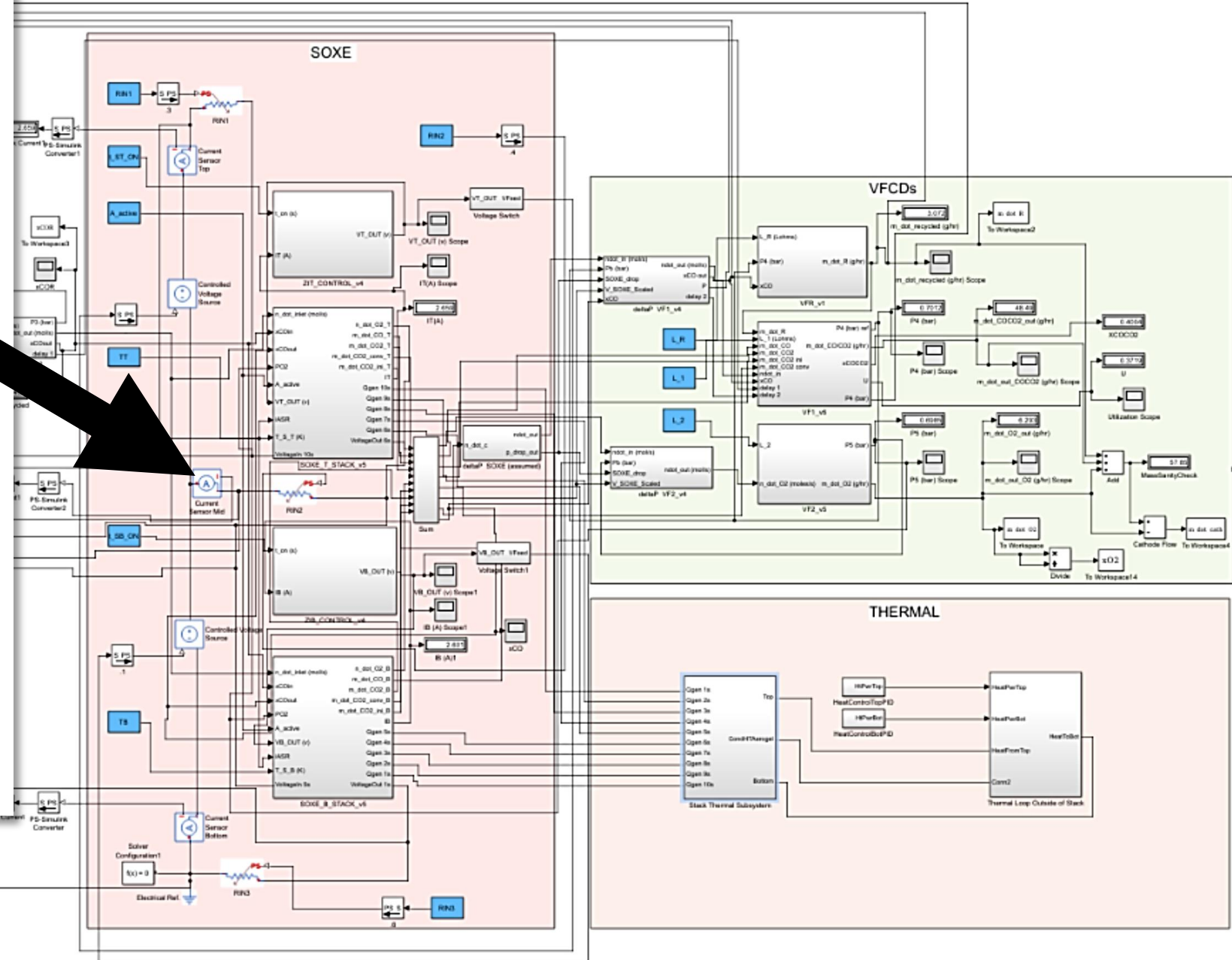
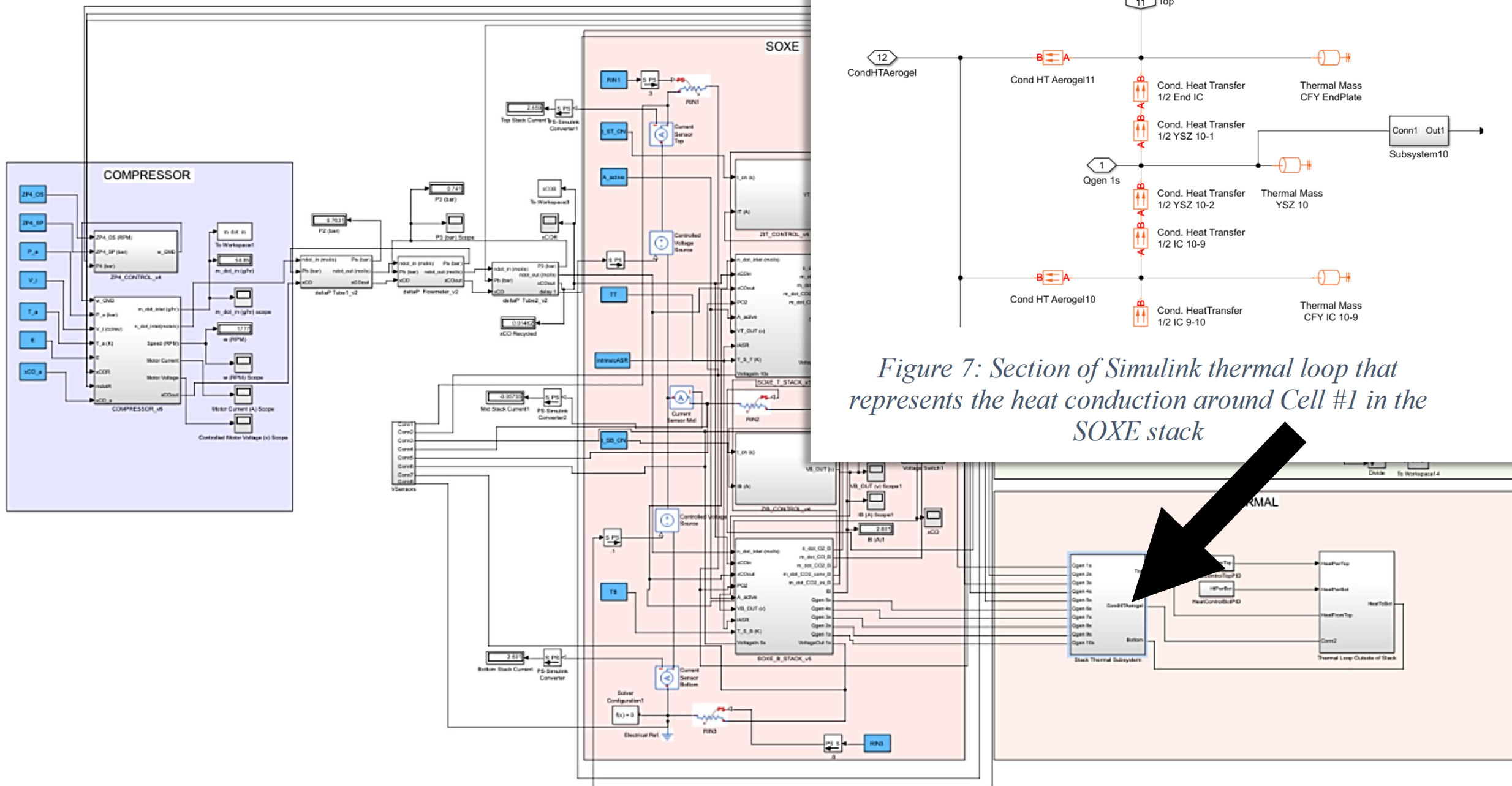


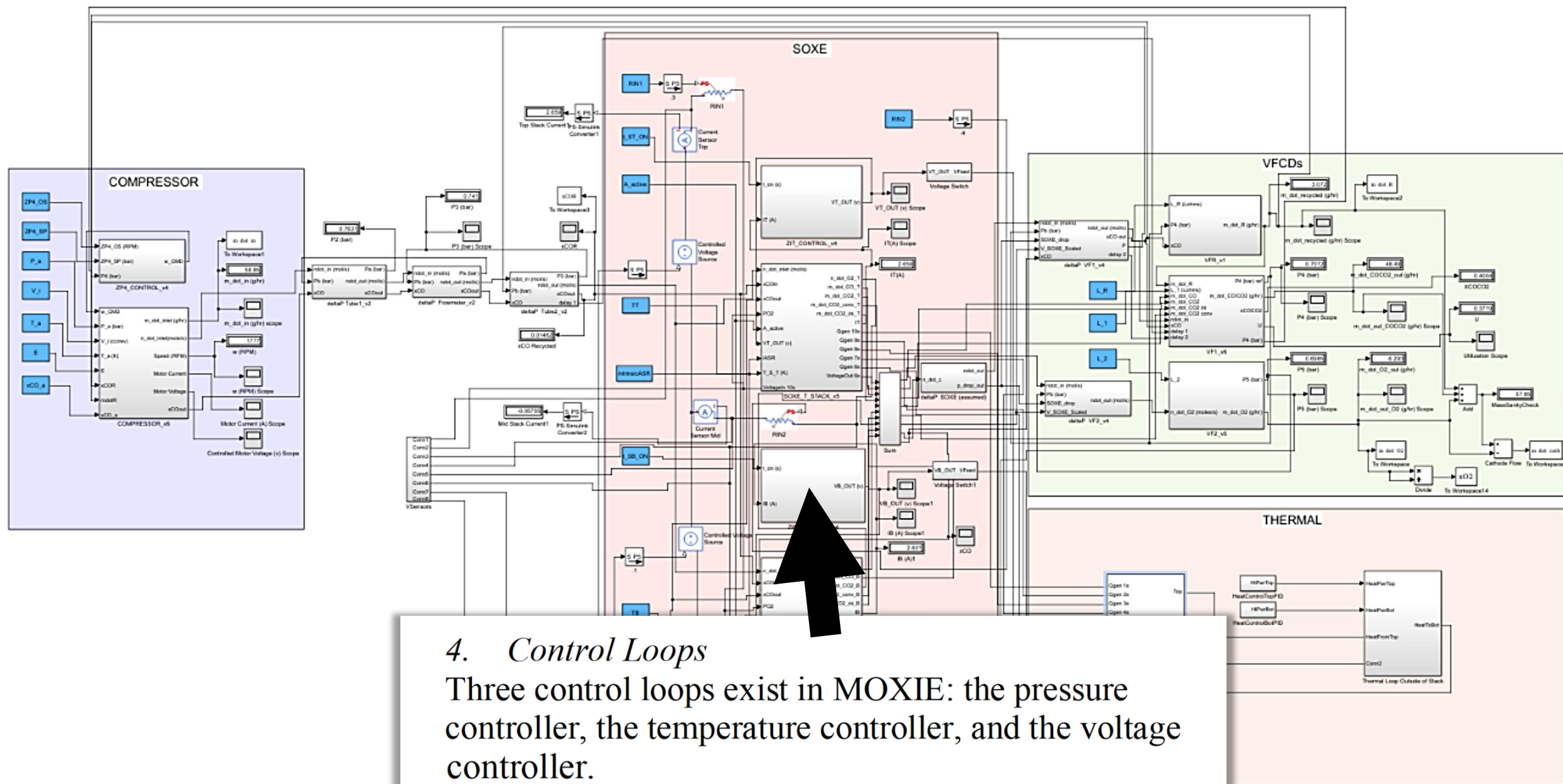
Figure 6: Simscape Electrical Loop of MOXIE







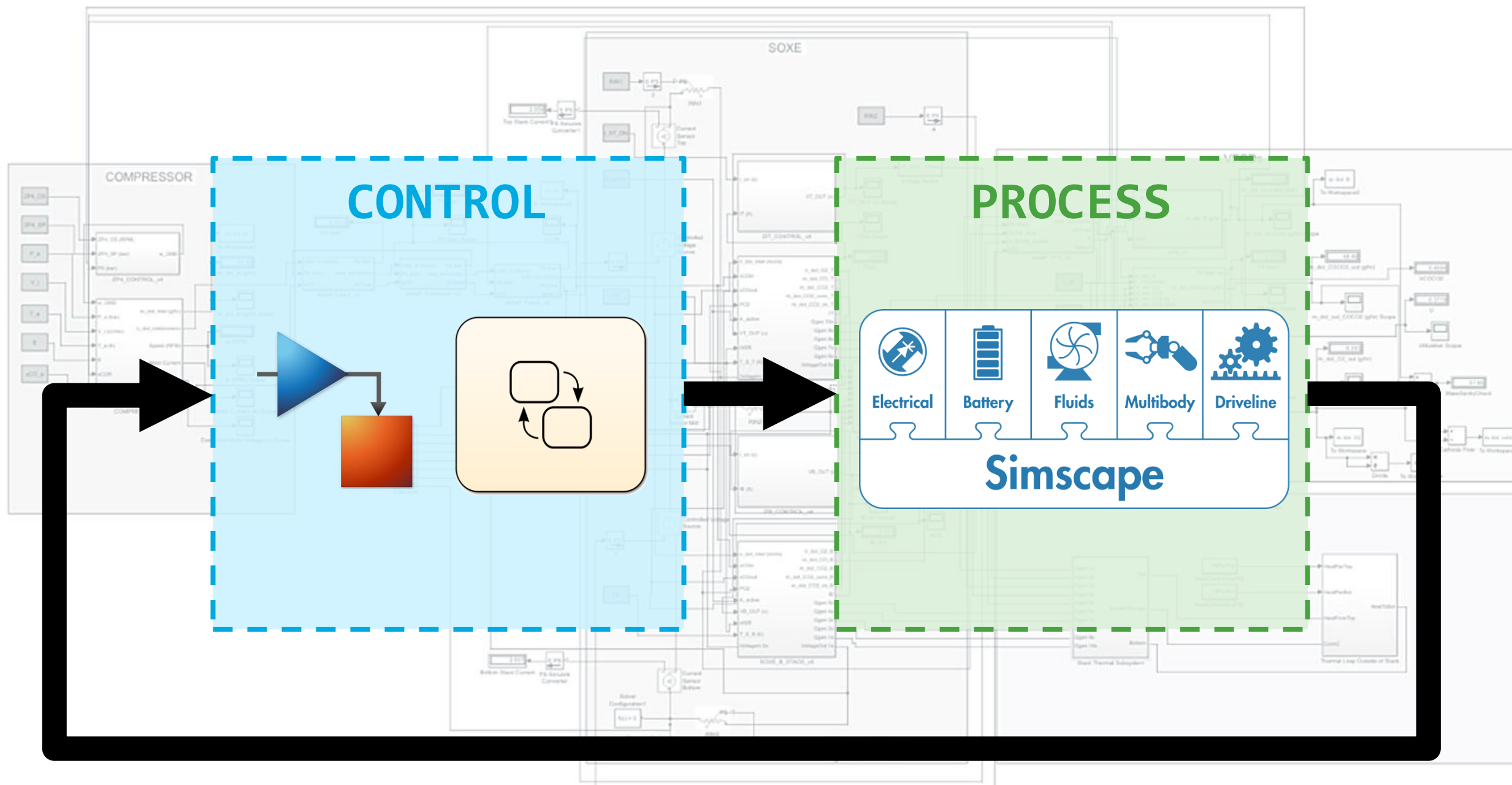
*Figure 7: Section of Simulink thermal loop that represents the heat conduction around Cell #1 in the SOXE stack*



#### 4. Control Loops

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

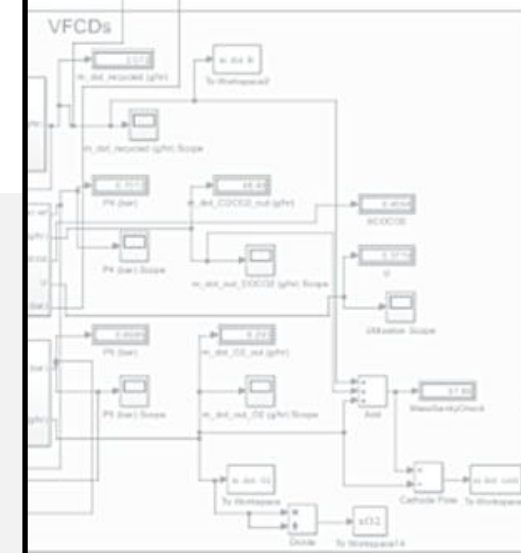
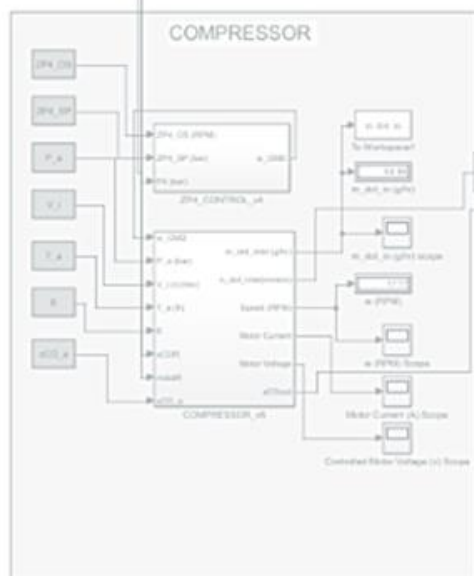




**IAC-18,A5,2,9x42905**  
**Simulating Oxygen Production on Mars for MOXIE (Mars Oxygen In-Situ Resource Utilization Experiment)**

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

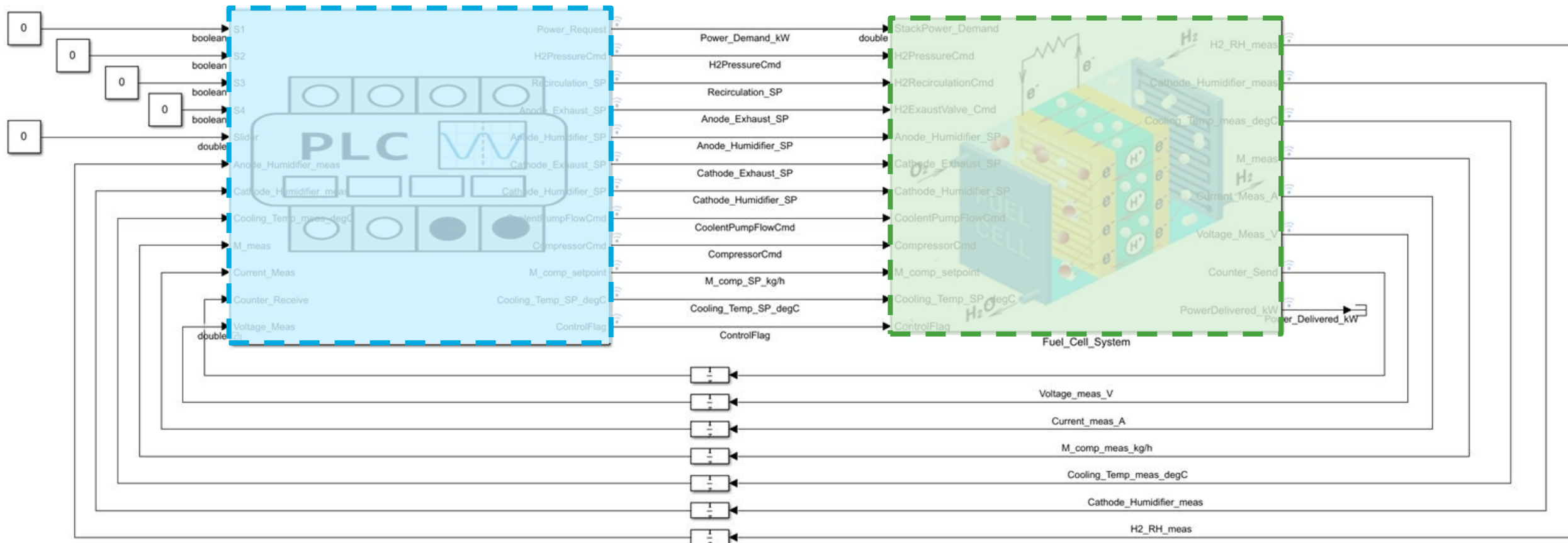
## 4. How Does the Model Work?



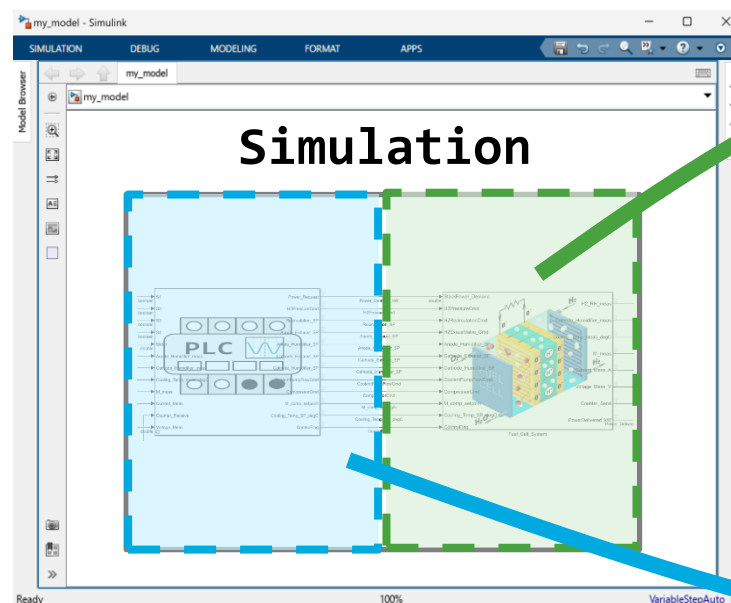


## CONTROL

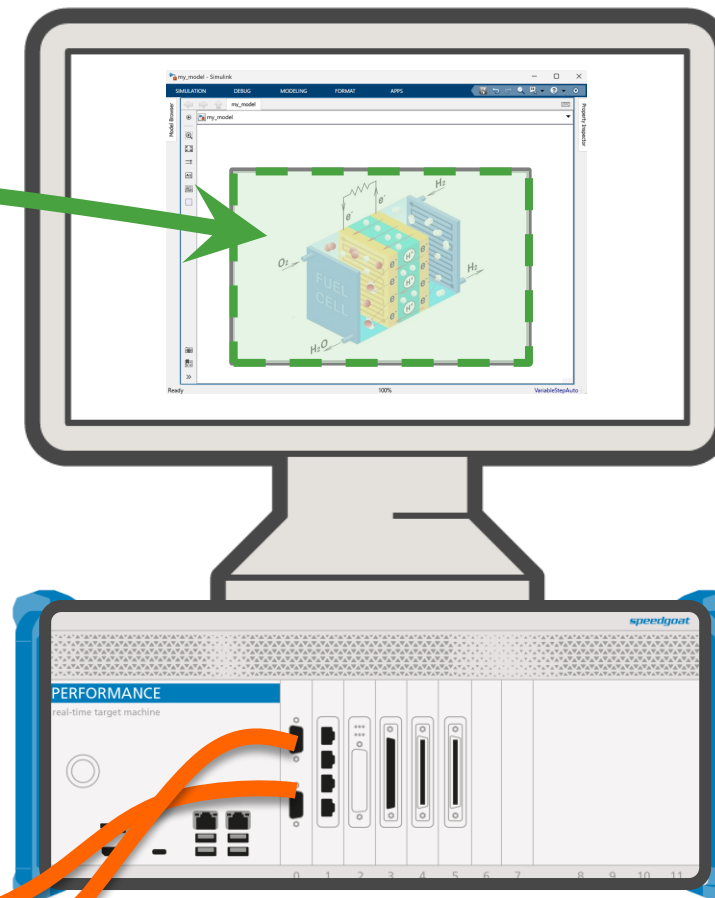
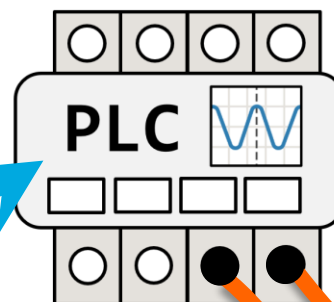
## PROCESS



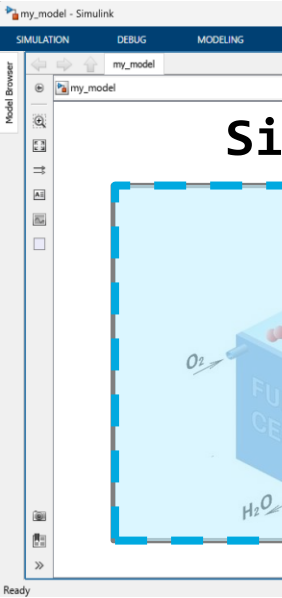
## Real-time Test

**CONTROL + PROCESS**

automatic  
code  
generation

**DIGITAL TWIN**



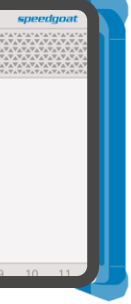


Si

CONTROL



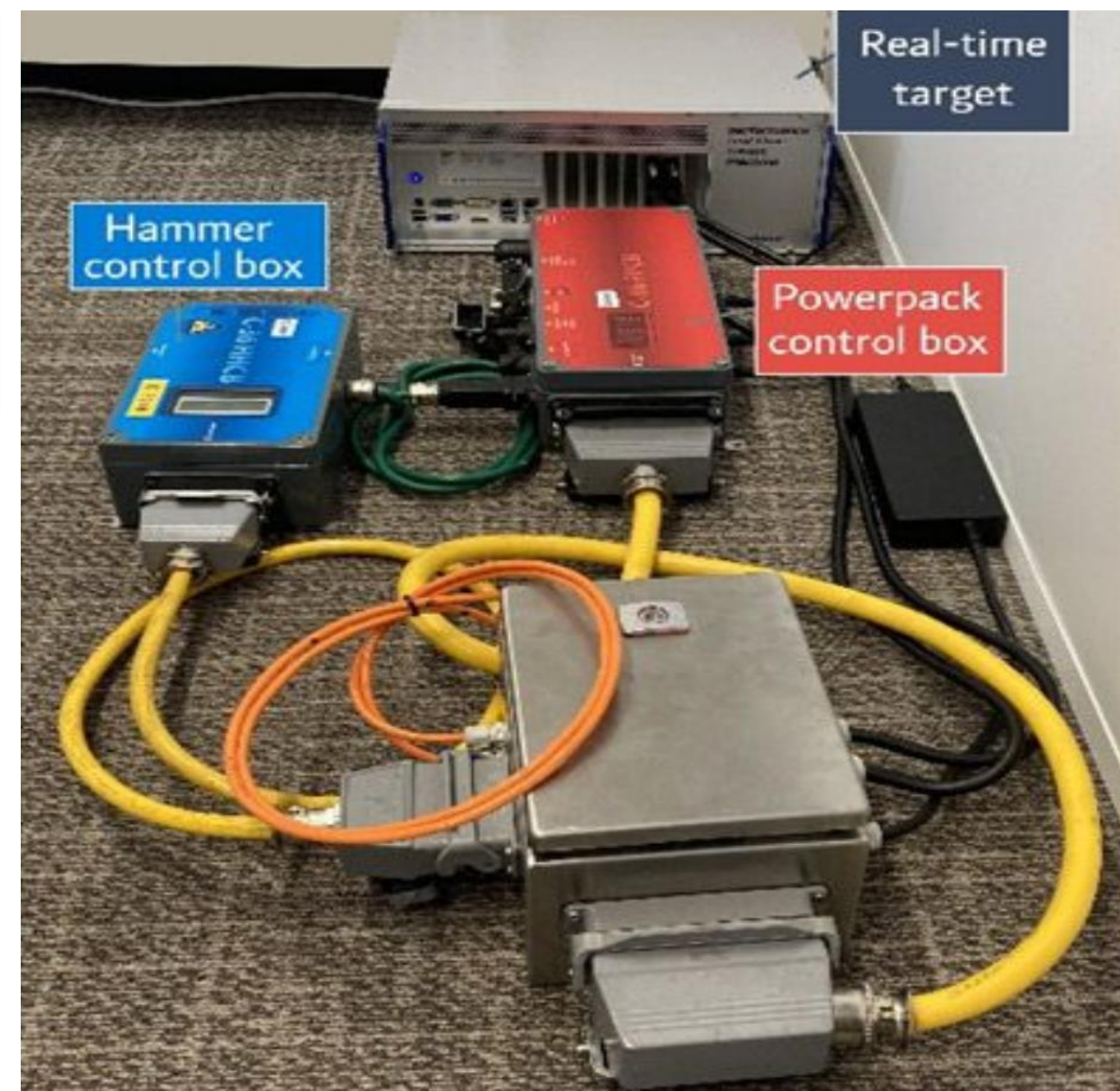
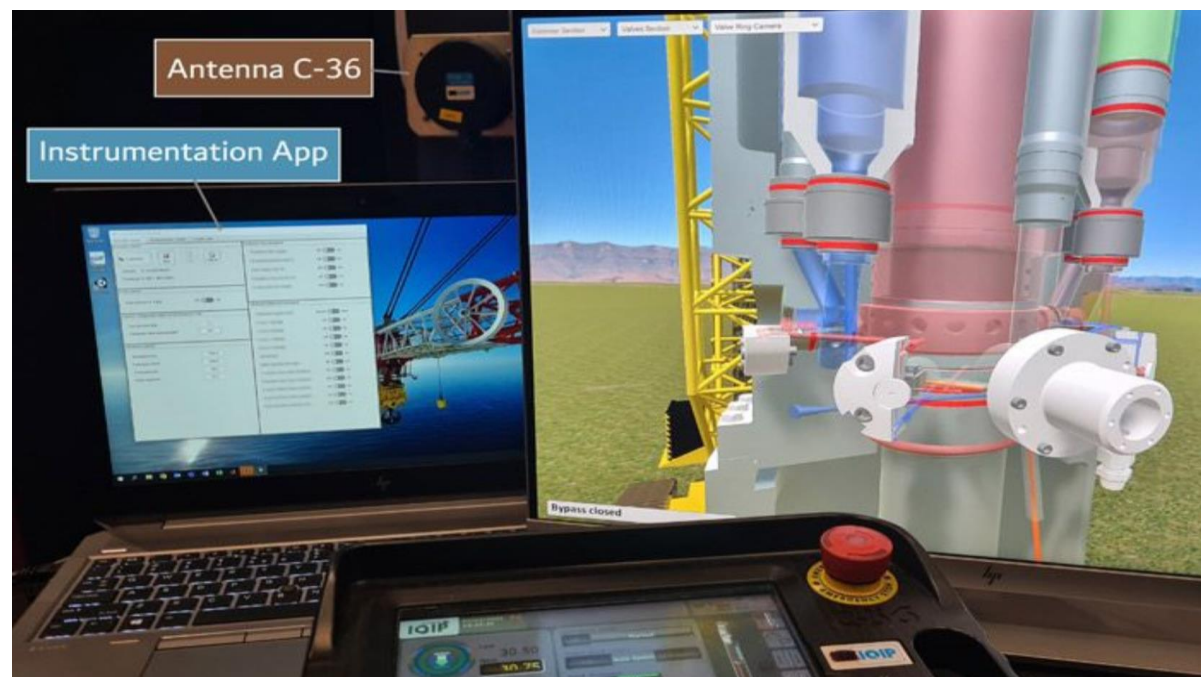
t



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







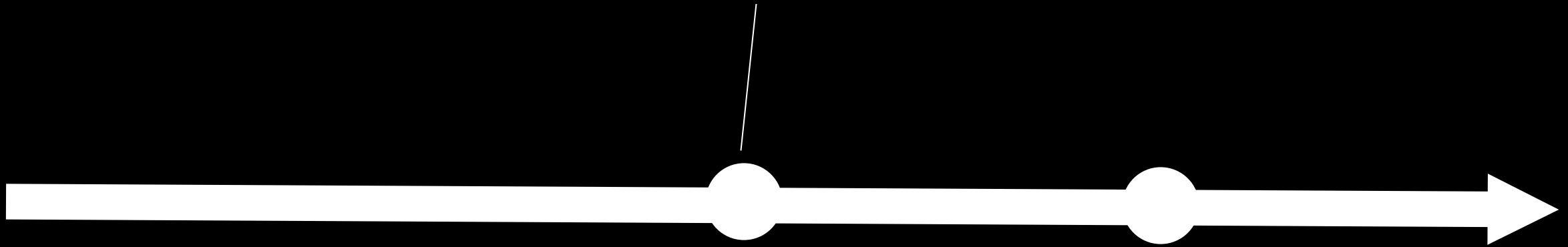
**Operations**

Reduced operating costs

Reduced risks

Test software without operation disruption

**Operations**



Understand how system behaves

Operator training

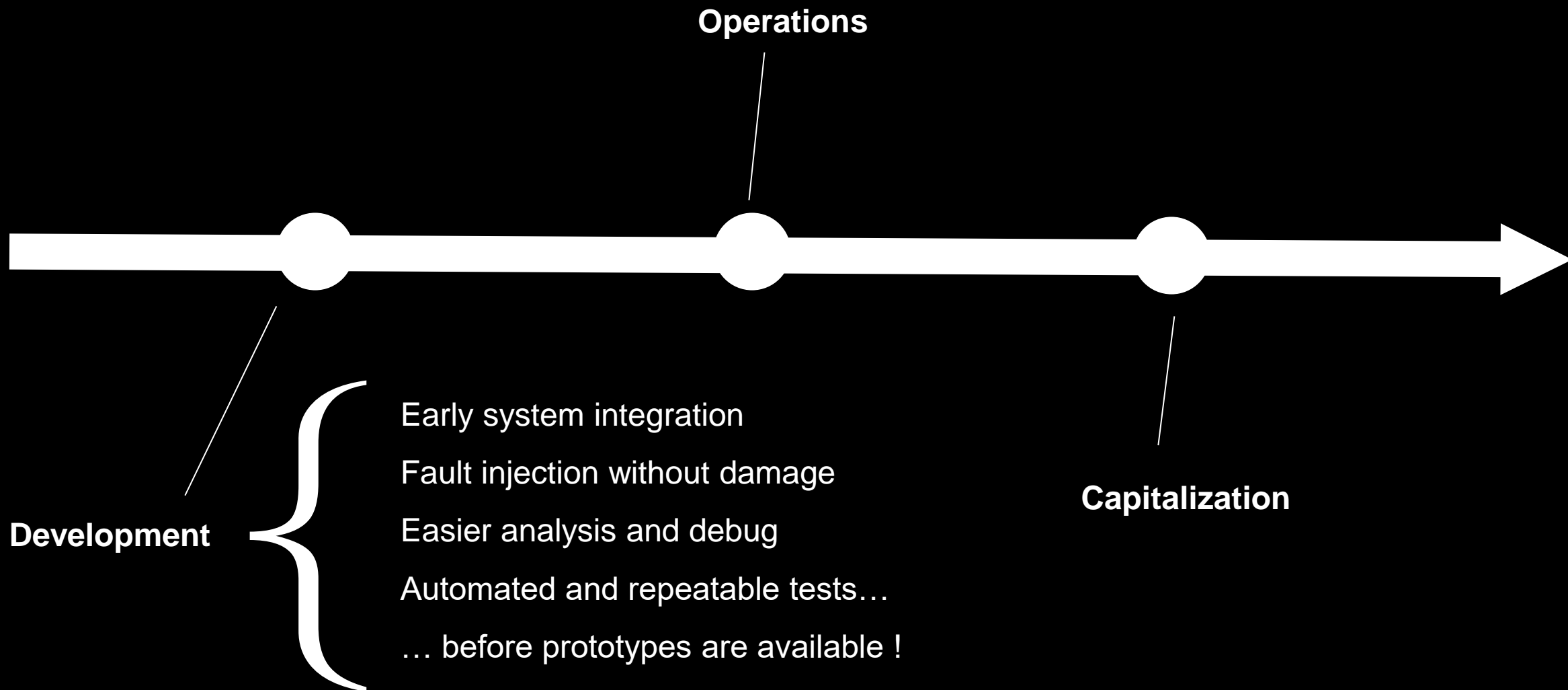
Reproduce issues from field data

What-if scenarios



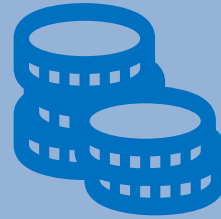
**Capitalization**







Short **agile**  
iteration cycles



**Saved** time  
and cost

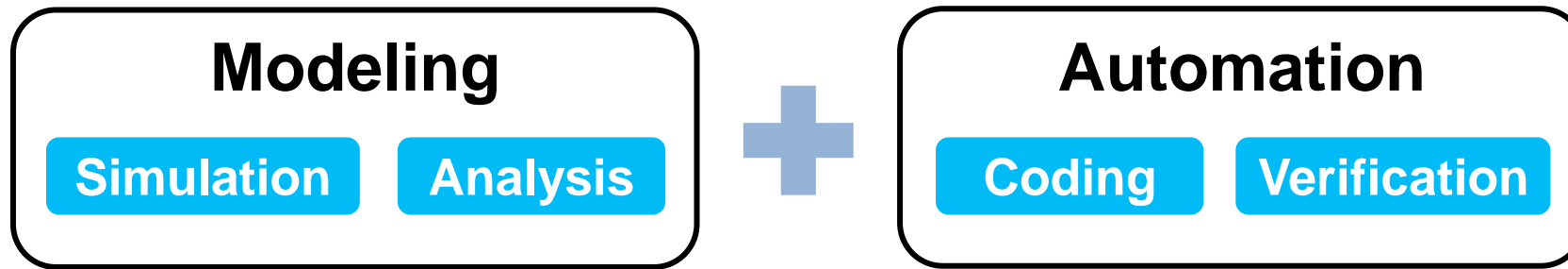


Minimal defects  
and **high quality**



# Model-Based Design

Systematic use of models throughout the development process



Short **agile**  
iteration cycles

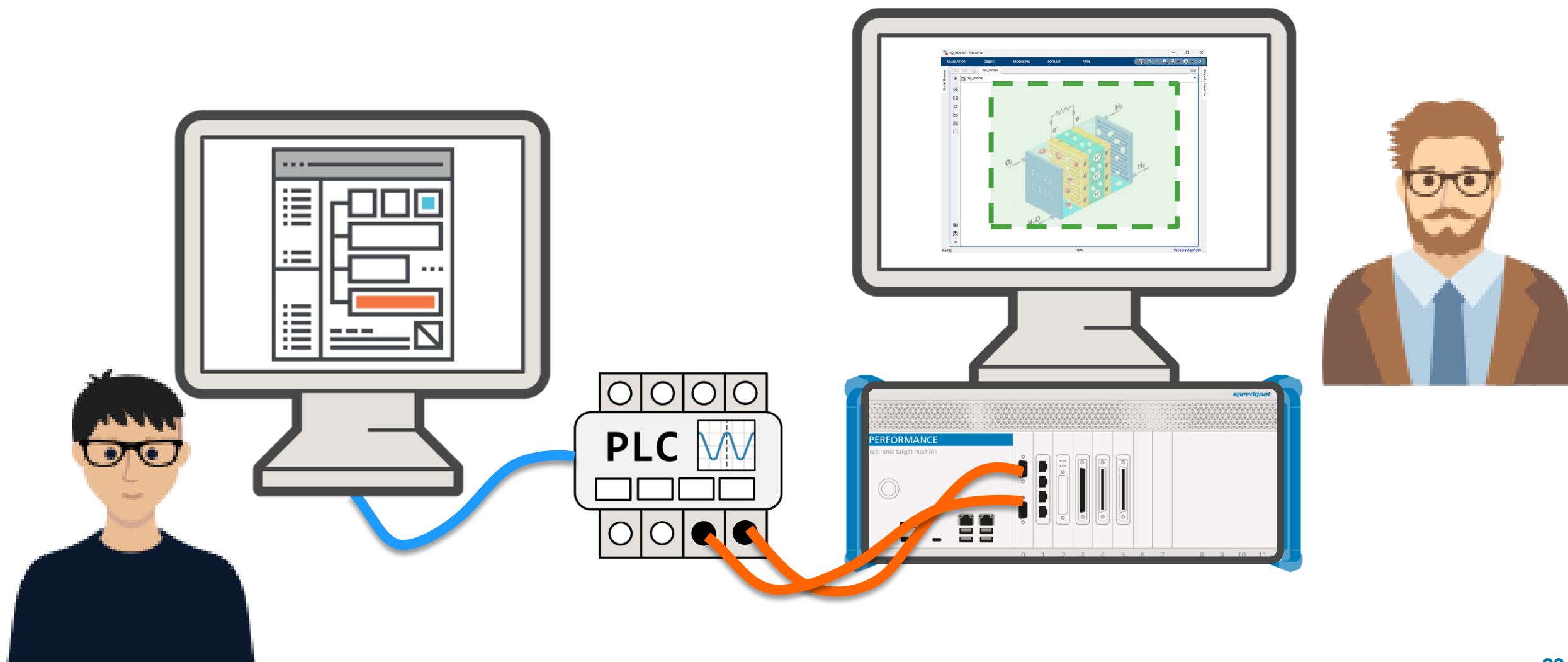


**Saved** time and  
cost



Minimal defects  
and **high quality**

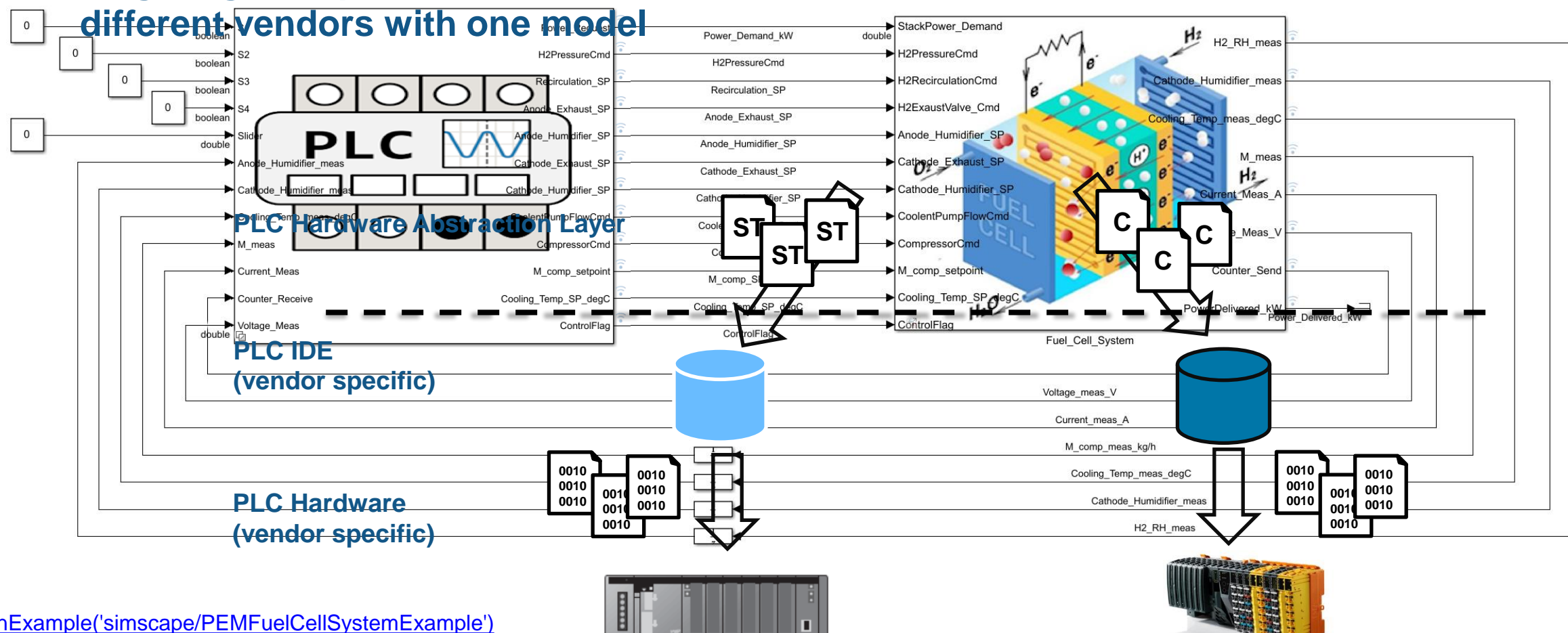
- ☑ Modeling and desktop simulation
- ☑ Code generation for PLC platforms
- ☑ Hardware in the loop





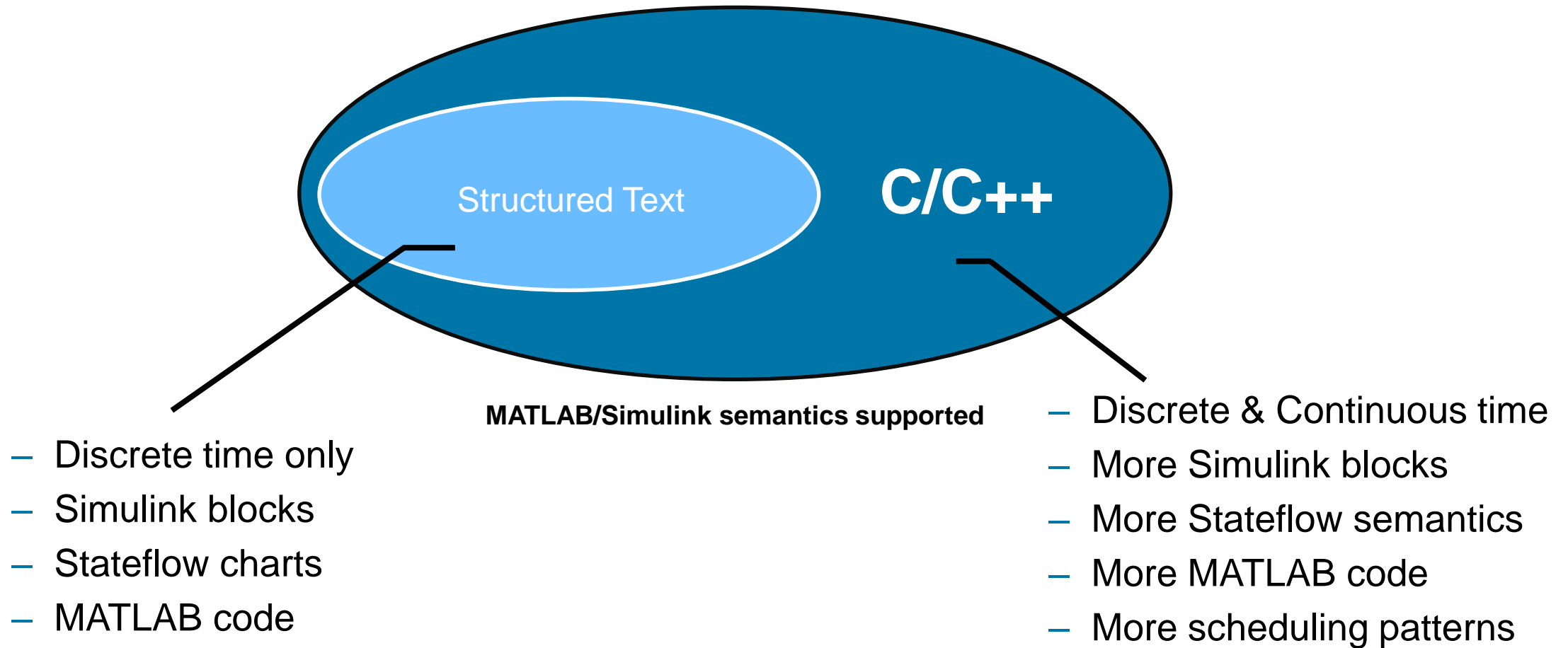
# Generate C/C++ or IEC 61131-3

Targeting multiple PLCs from  
different vendors with one model



[openExample\('simcape/PEMFuelCellSystemExample'\)](#)

## Generate C/C++ or IEC 61131-3



### PLC Code Generation

Generate Structured Text code using Simulink® PLC Coder™.

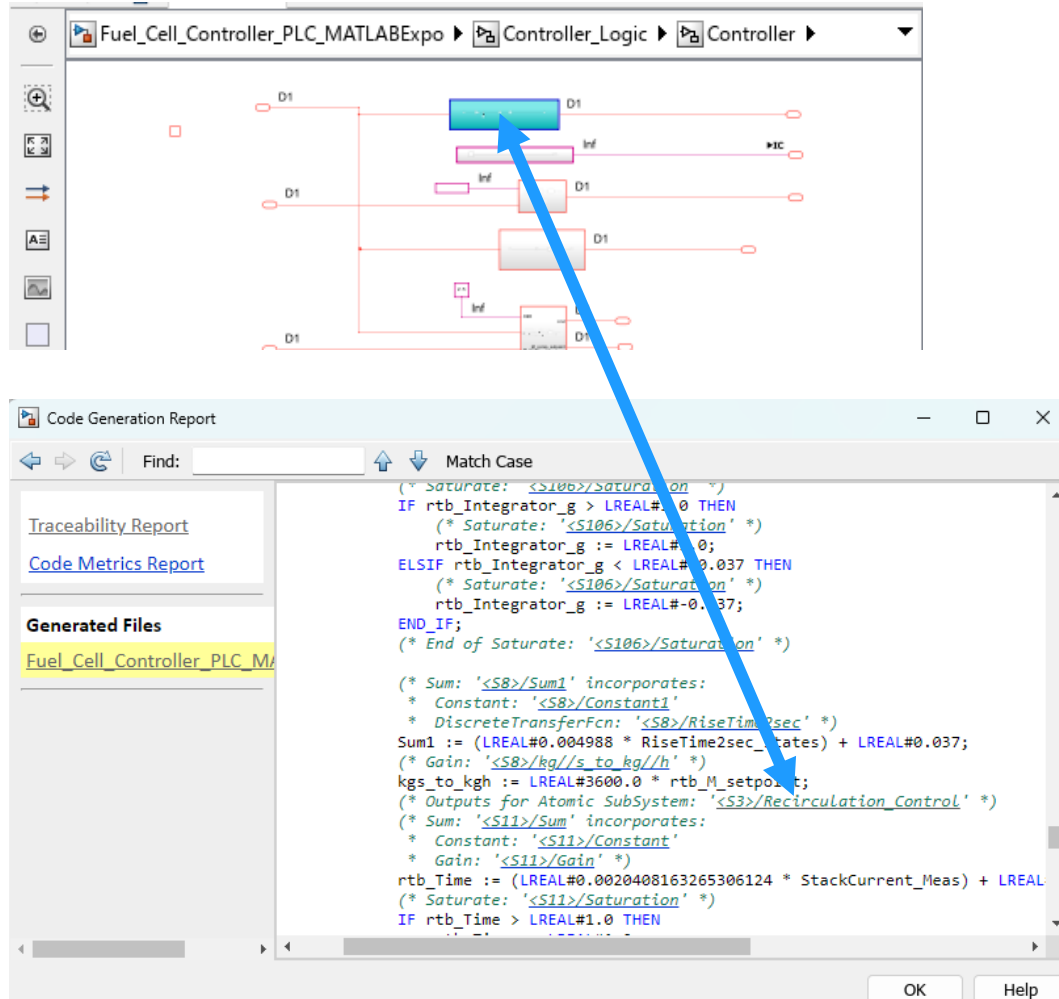
### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

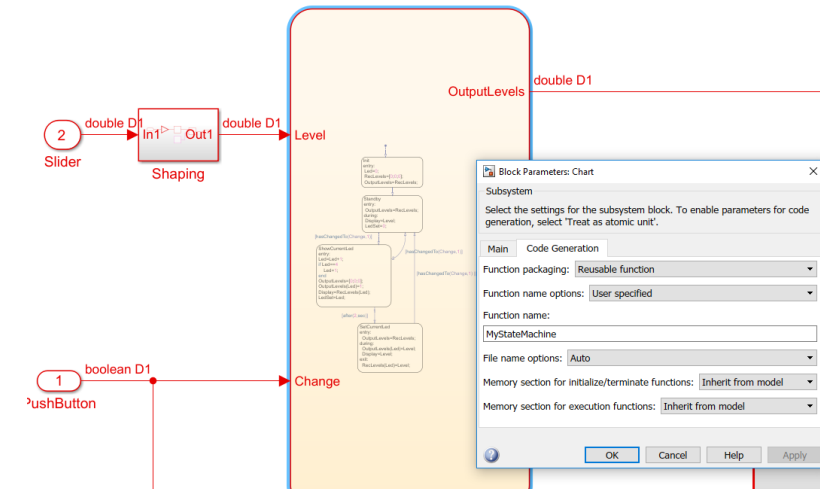
# C/C++ & IEC 61131-3

## 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)
- ...



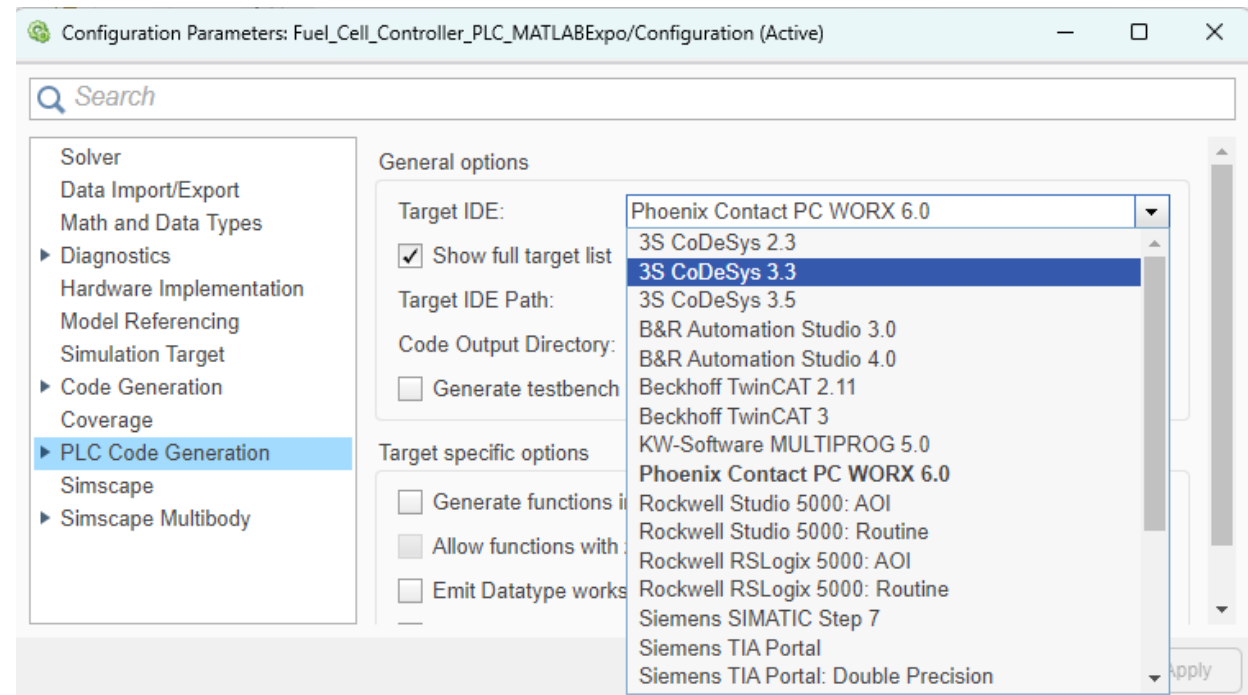
# Generate Structured Text

- Generate IEC 61131-3 Structured Text from

- Simulink models
- Stateflow charts
- MATLAB code

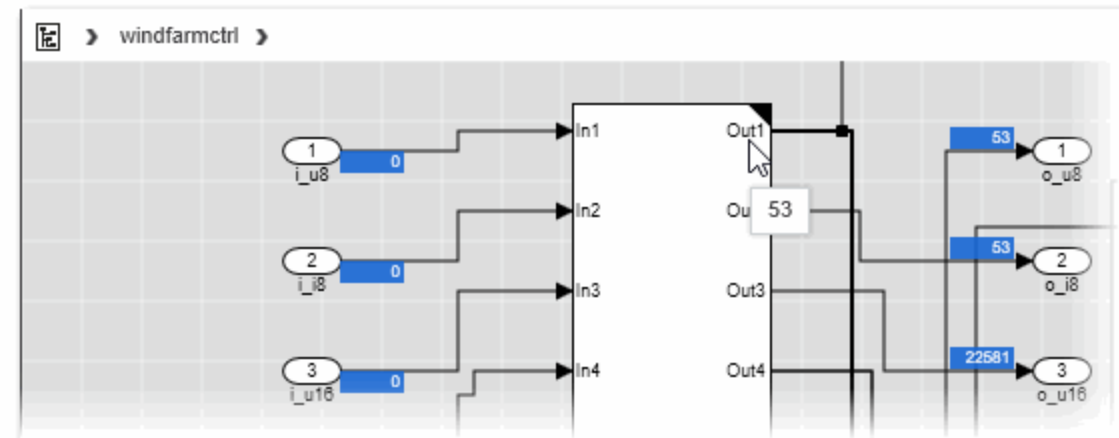
- Generate Structured Text for

- Rockwell Automation Studio 5000
- Siemens STEP 7/TIA Portal
- 3S CODESYS
- [Many other IDEs and PLCs](#)

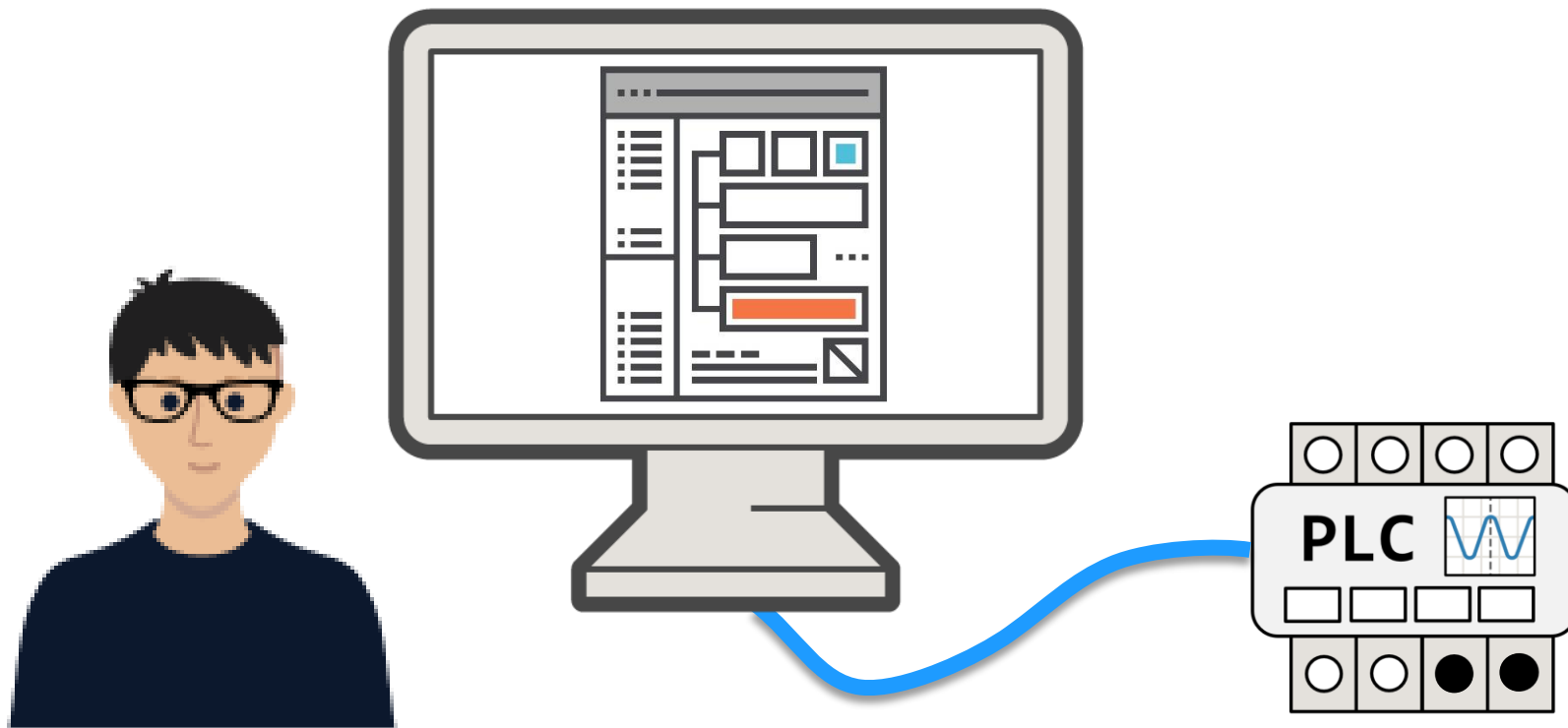


## Generate C/C++ code

- 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
  - ...

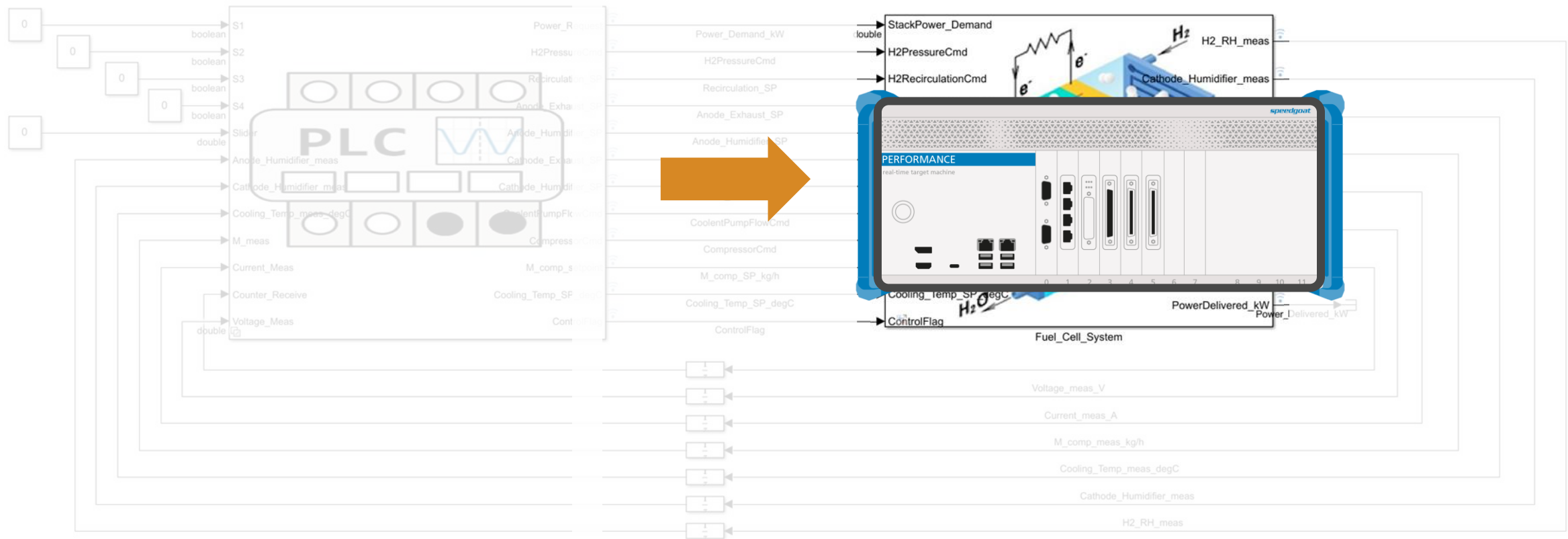


Integrate automatically generated code into the PLC software through the vendor's IDE

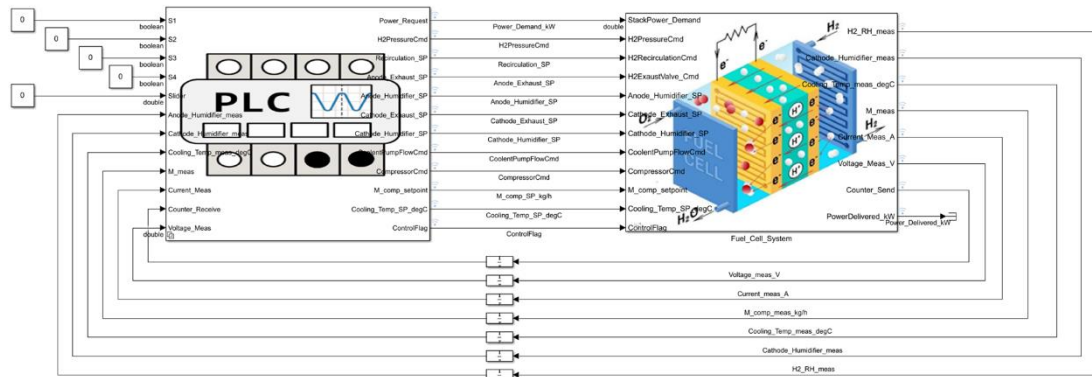




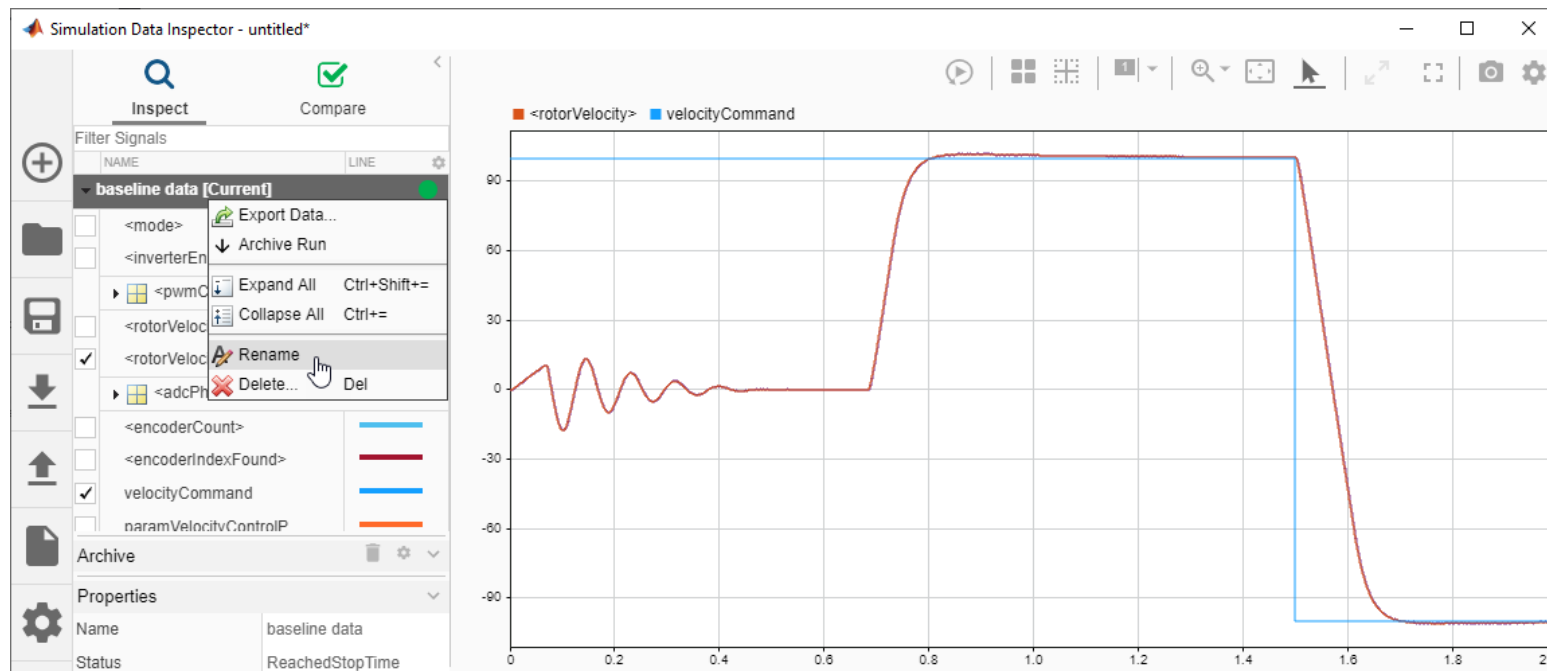
# Hardware-In-the-Loop



# From Desktop Simulation to Real-Time



`auto(ode23t)`



# From Desktop Simulation to Real-Time

**Solver**

- Data Import/Export
- Math and Data Types
- ▼ Diagnostics
  - Sample Time
  - Data Validity
  - Type Conversion

Simulation time

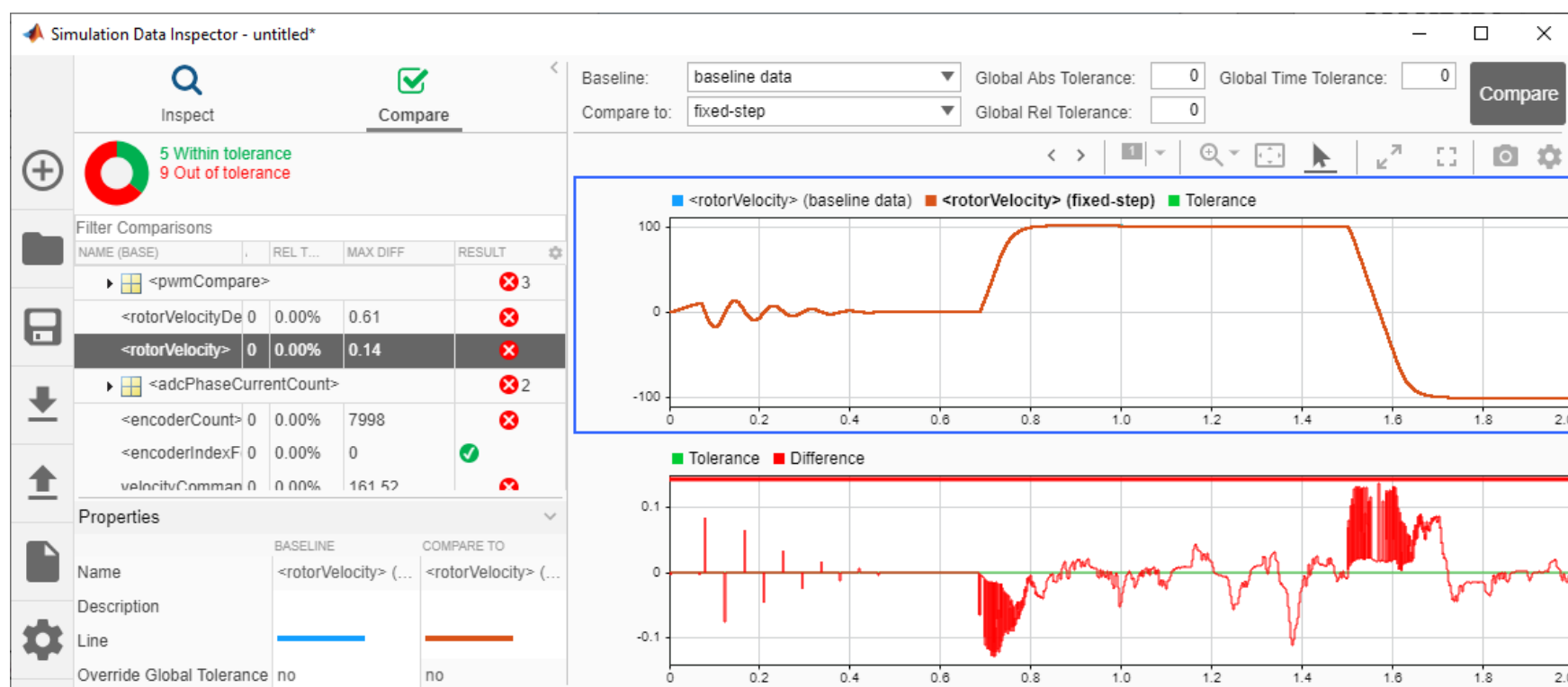
Start time: 0.0 Stop time: 2

Solver selection

Type: **Fixed-step** Solver: auto (Automatic solver selection)

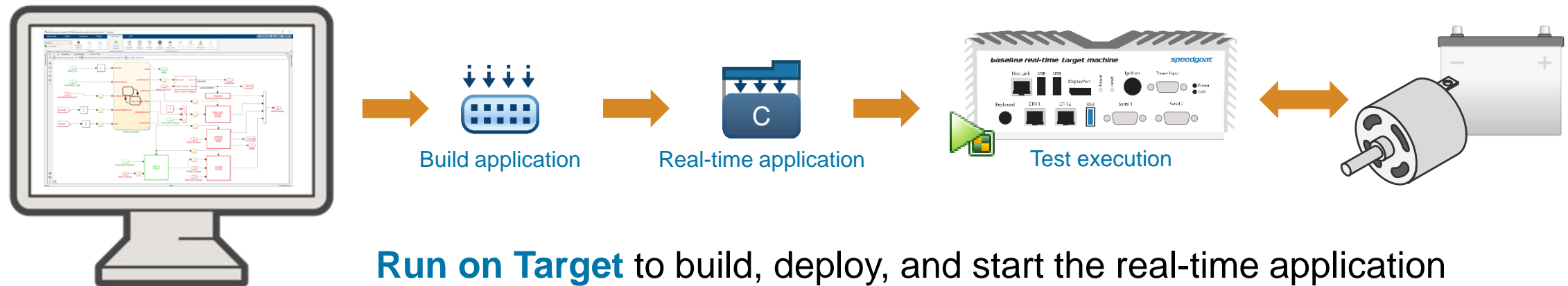
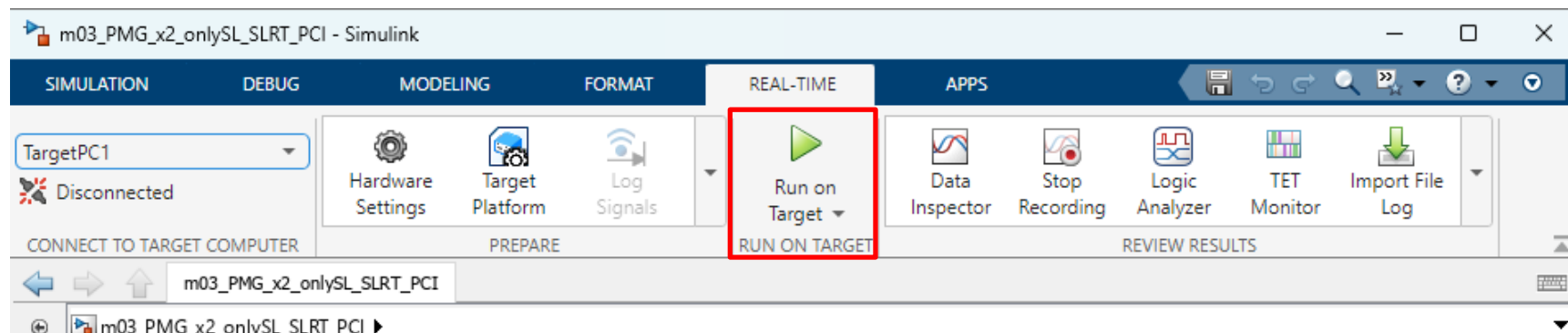
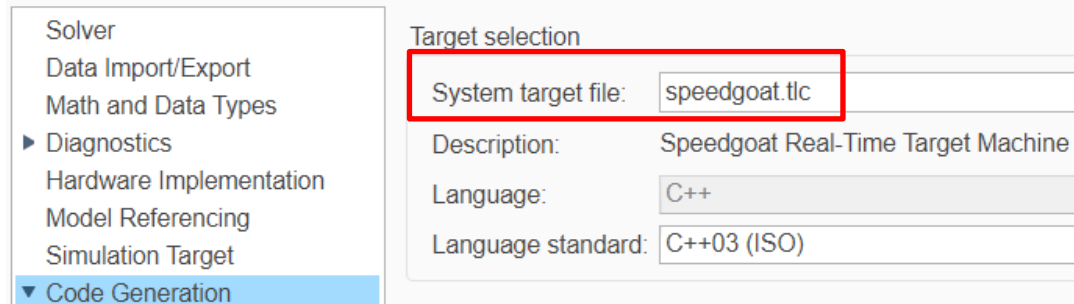
Run

`auto(ode14x)`





# From Desktop Simulation to Real-Time



# 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)
```

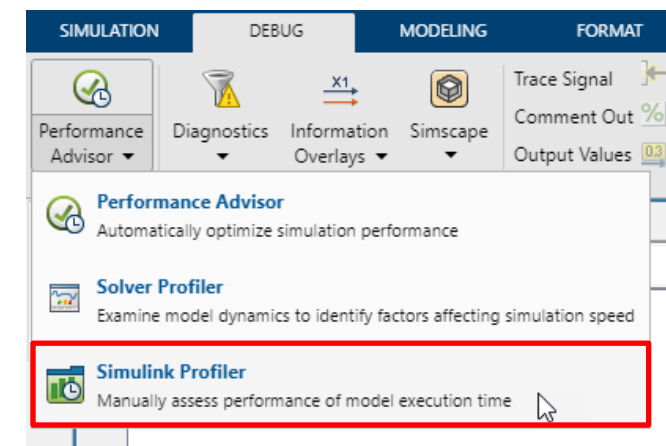
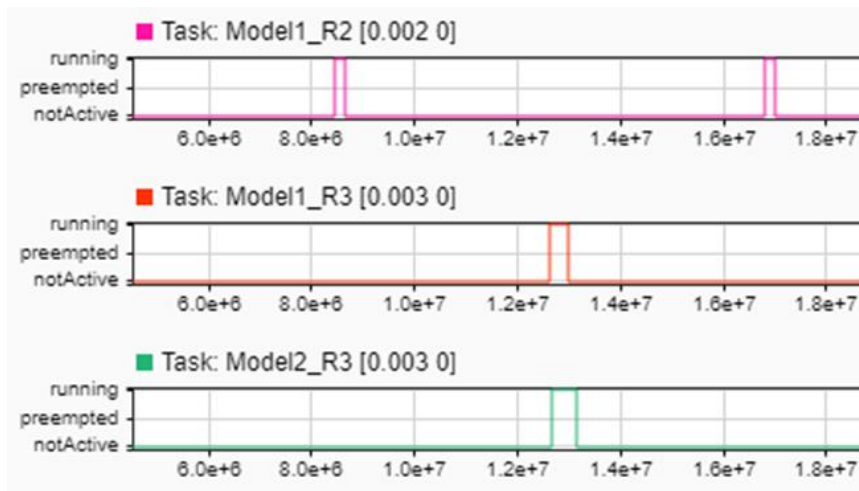
```
ans =
```

```
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

```



Profiler Report (pmsm\_sysHarness11\_hil\_opt\_start @ 25-Nov-2020 18:59:58)

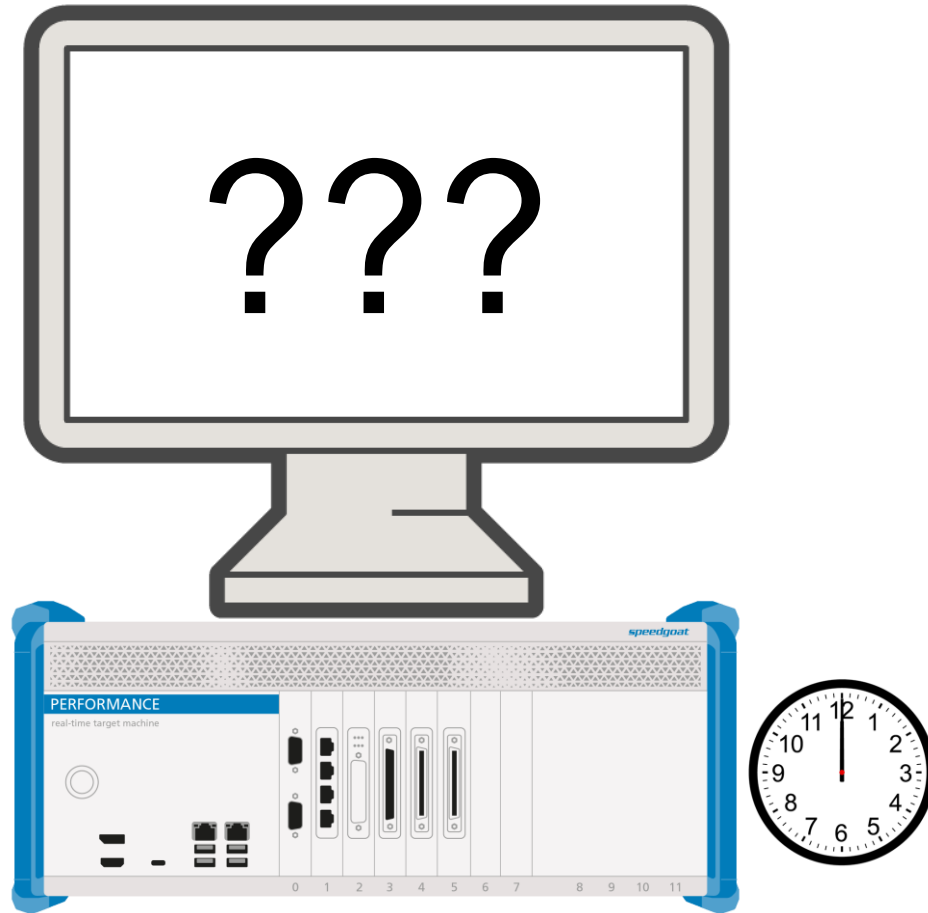
Run: pmsm\_sysHarness11\_hil\_opt\_start @ 25-Nov-2020 18:59:58

Path	Time Plot (Dark Band = Self Time)	Total Time (s)	Self Time (s)
pmsm_sysHarness11_hil_opt_start		50.894	11.516
System_Under_Test		26.093	2.397
Plant_Model		17.938	2.089
PMSM_Physical_Model		11.557	0.000
...sm_plant07_sse_opt_start		3.299	3.299
ADC_Current_Speedgoat		0.471	0.000
Condition Encoder		0.252	0.000
...er_Sensor_And_Peripheral		0.201	0.000
Bus Creator1		0.045	0.045
Data Type Conversion		0.024	0.024
Controller_Algorithm		3.408	0.148
pmsm_sut_hil00_opt_start		1.825	1.825
Discrete_To_Continuous		0.252	0.000
Continuous_To_Discrete		0.227	0.000
Rate Transition		0.046	0.046



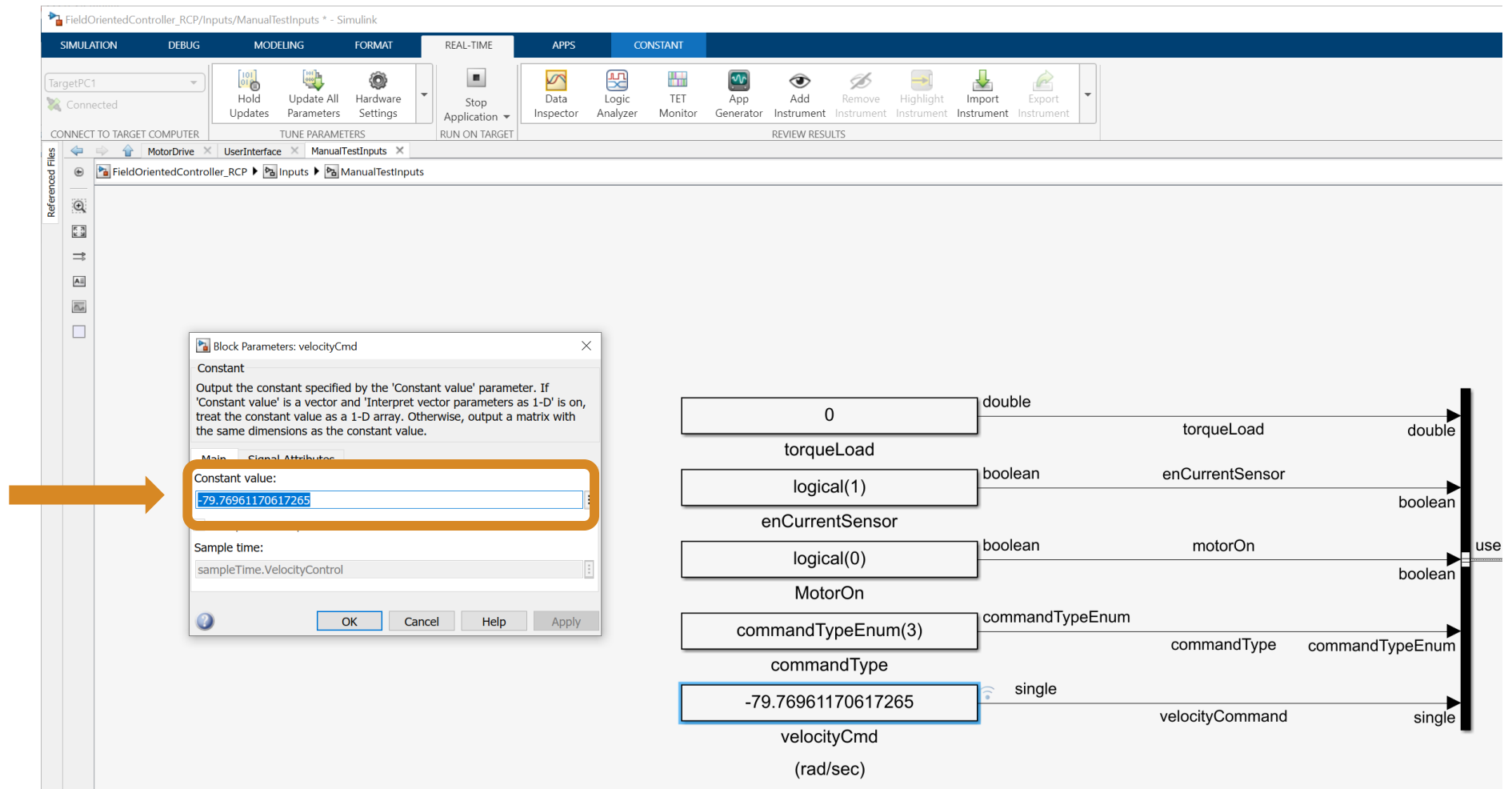


# Debug real-time algorithms

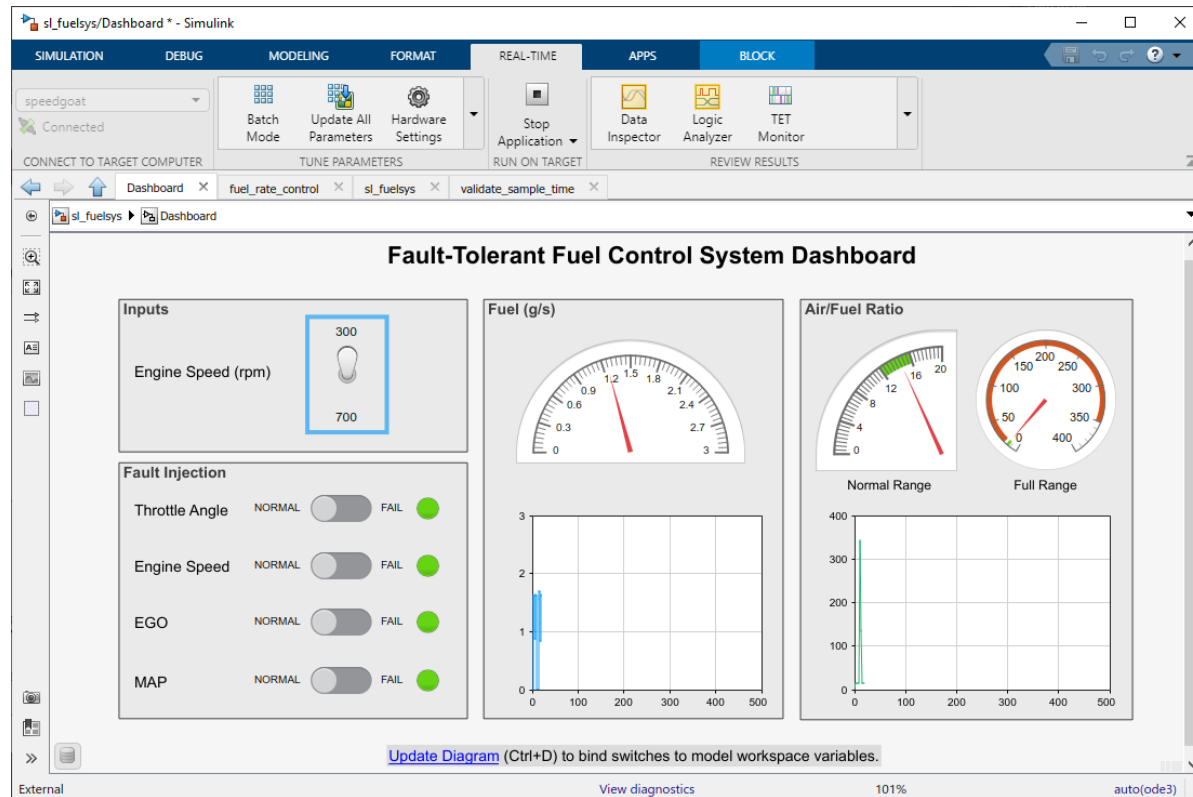


# Debug real-time algorithms directly from Simulink

Tune parameters from the  
Simulink interface



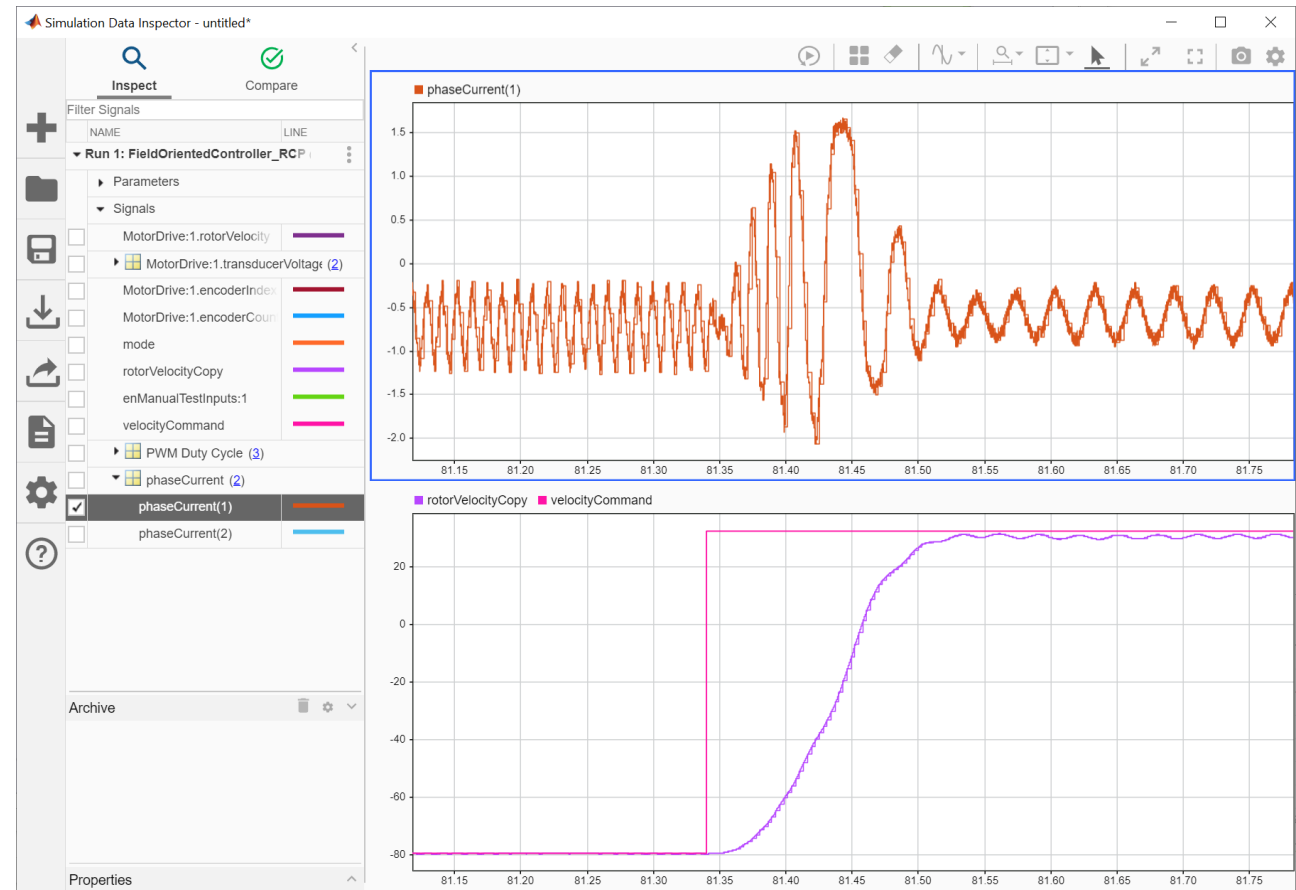
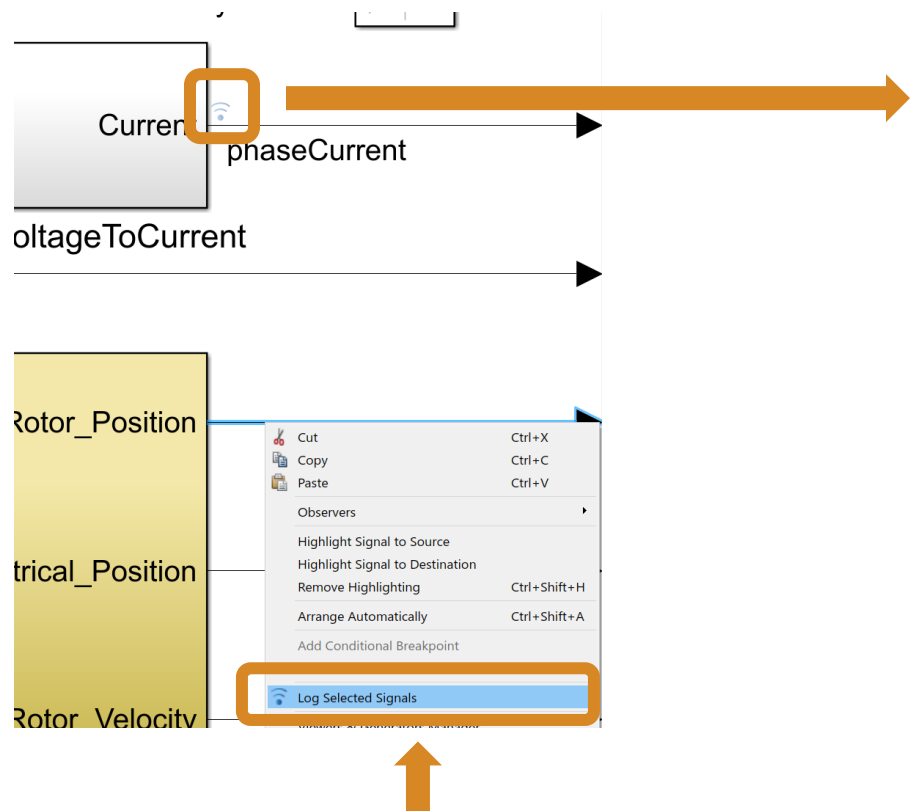
# Debug real-time algorithms directly from Simulink



The screenshot shows the 'Test Manager' interface with the 'MIL Closed Loop' test selected. The interface is divided into several sections:

- TESTS:** A toolbar with icons for New, Open, Save, Cut, Copy, Paste, Delete, Test Spec Report, Run, Run with Stepper, Stop, Parallel, Report, Visualize, Highlight in Model, Export, and Model Testing Dashboard.
- Test Browser:** A tree view showing the test hierarchy: PMSM\_Testsuite > PMSM\_Tests > MIL Closed Loop. A context menu is open over 'MIL Closed Loop' with options like 'Open in Tab', 'Run', 'Run Selected in', 'Create Report', 'Expand All', 'Collapse All', 'Move Up', 'Move Down', 'Cut', 'Copy', 'Paste', 'Enabled', 'Delete', 'Rename', and 'Convert to'.
- Results and Artifacts:** A section for viewing test results and artifacts.
- MIL Closed Loop:** A detailed view of the test configuration, including:
  - Simulation Test:** A checkbox to 'Create Test Case from External File'.
  - TAGS:** A section for tags.
  - DESCRIPTION:** A section for description.
  - REQUIREMENTS\*:** A section for requirements.
  - SYSTEM UNDER TEST\*:** A section for the system under test, with fields for 'Model' (PMSM\_desktopModel) and 'Harness' (PMSM\_desktopModel\_Harness\_testSeq).
  - SIMULATION SETTINGS AND RELEASE OVERRIDES:** A section for simulation settings and release overrides.
  - PARAMETER OVERRIDES\*:** A section for parameter overrides.
  - CALLBACKS\*:** A section for callbacks.
  - INPUTS:** A section for inputs.
  - SIMULATION OUTPUTS:** A section for simulation outputs.
  - CONFIGURATION SETTINGS OVERRIDES:** A section for configuration settings overrides.
  - SETTINGS:** A section for settings.
  - ITERATIONS\*:** A section for iterations.

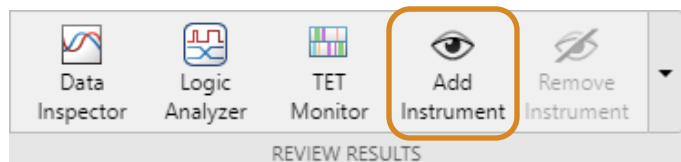
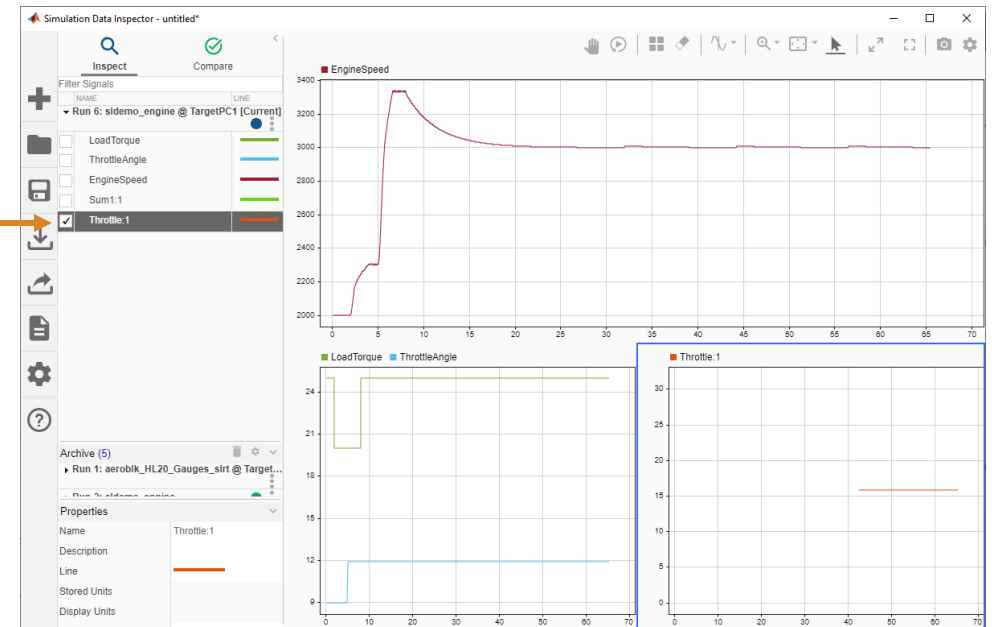
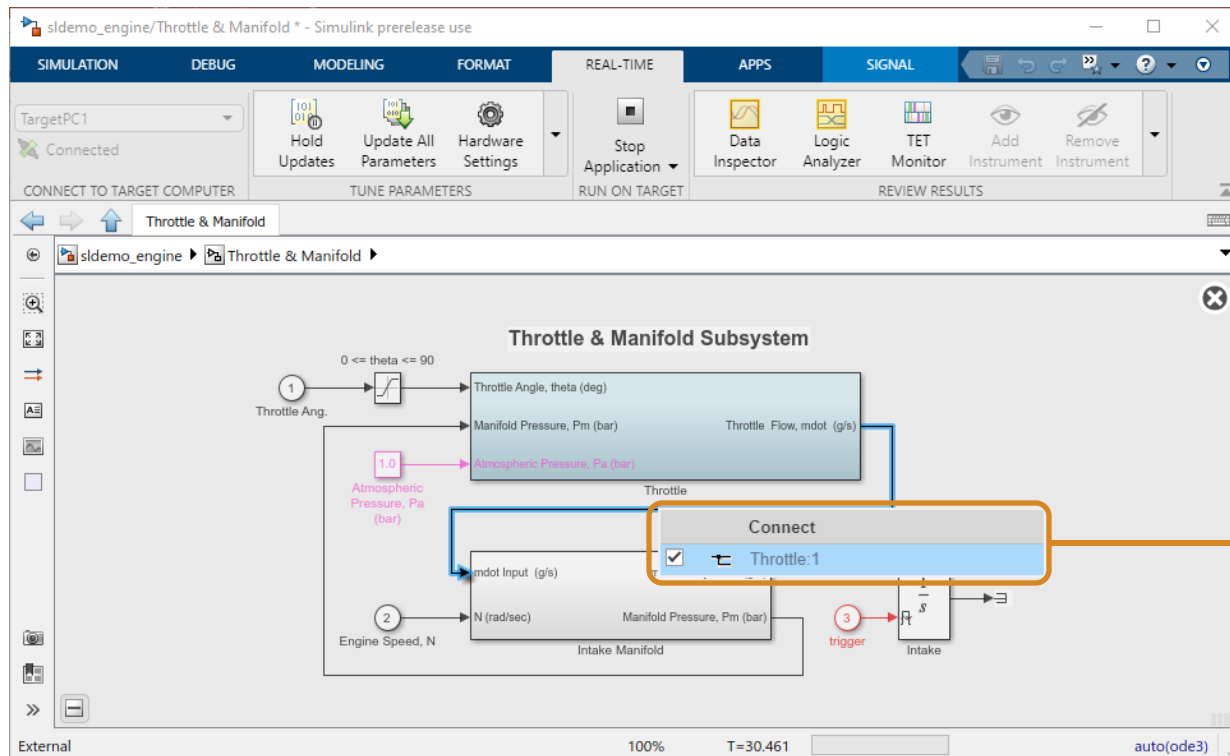
# Debug real-time algorithms directly from Simulink



Select signals to log/view in Simulation Data Inspector

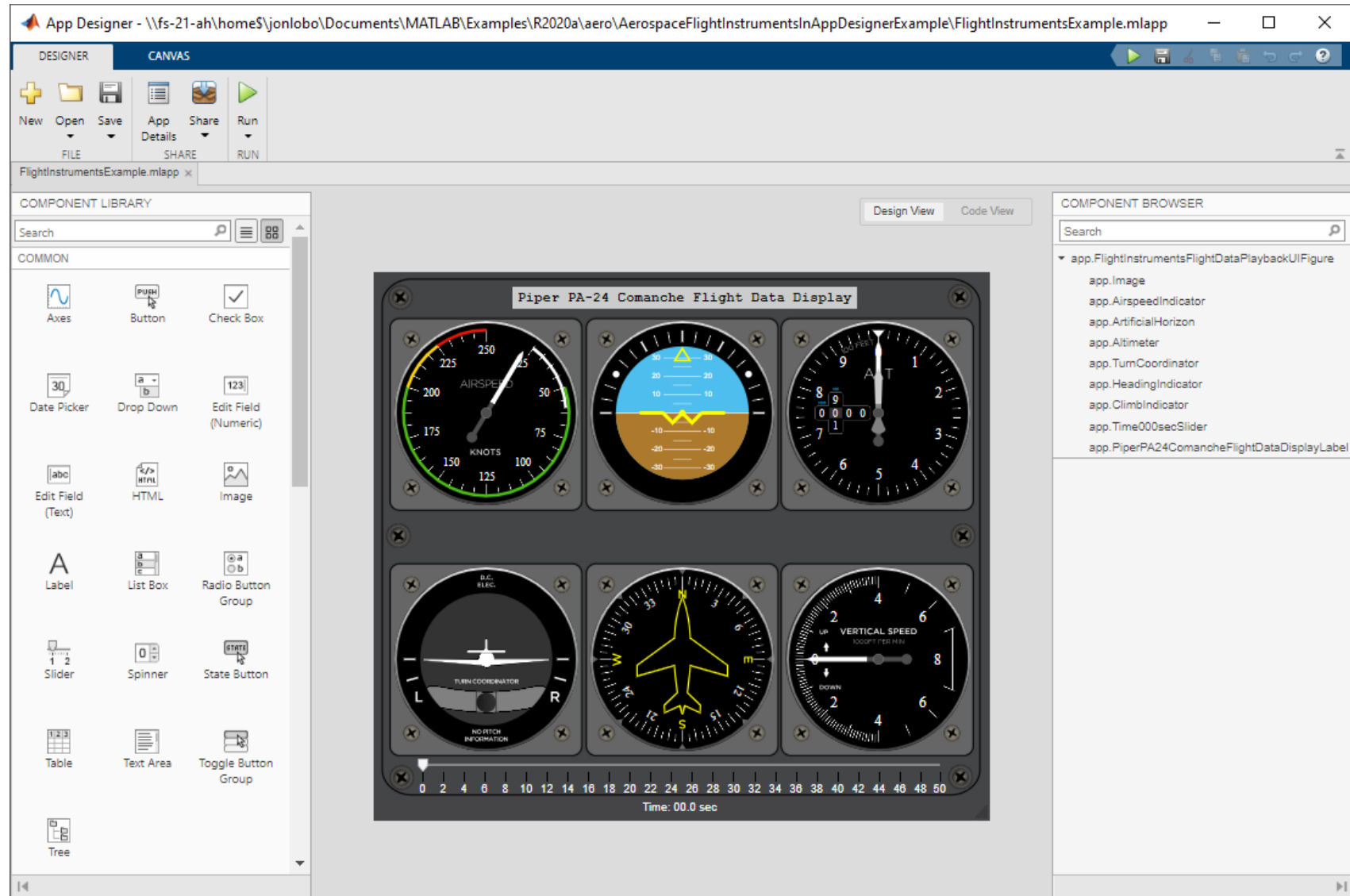


# Debug real-time algorithms directly from Simulink





# Debug real-time algorithms with dedicated application



# Connect the virtual machine to the PLC over an industrial fieldbus

The image displays the Simulink environment for configuring a virtual machine (VM) to connect to a PLC over an industrial fieldbus. The main workspace shows a Simulink model with a 'controllerOutput' block connected to a 'double' block, which is then connected to a 'Speedgoat IO397-50k Digital Output v1' block. The output of the digital output block is connected to a 'Speedgoat IO397-50k PWM Generation v5' block. The 'double' block has a gain of  $\text{Gain} = 1/\text{pwmCounterMax}$ .

On the left, the 'Simulink Library Browser' shows the 'Speedgoat I/O Blockset/IO3xx/PWM' section. The 'PWM' block is highlighted. The 'Block Parameters: PWM generation (5)' dialog box is open on the right, showing the 'PWM generation' tab. The parameters are configured as follows:

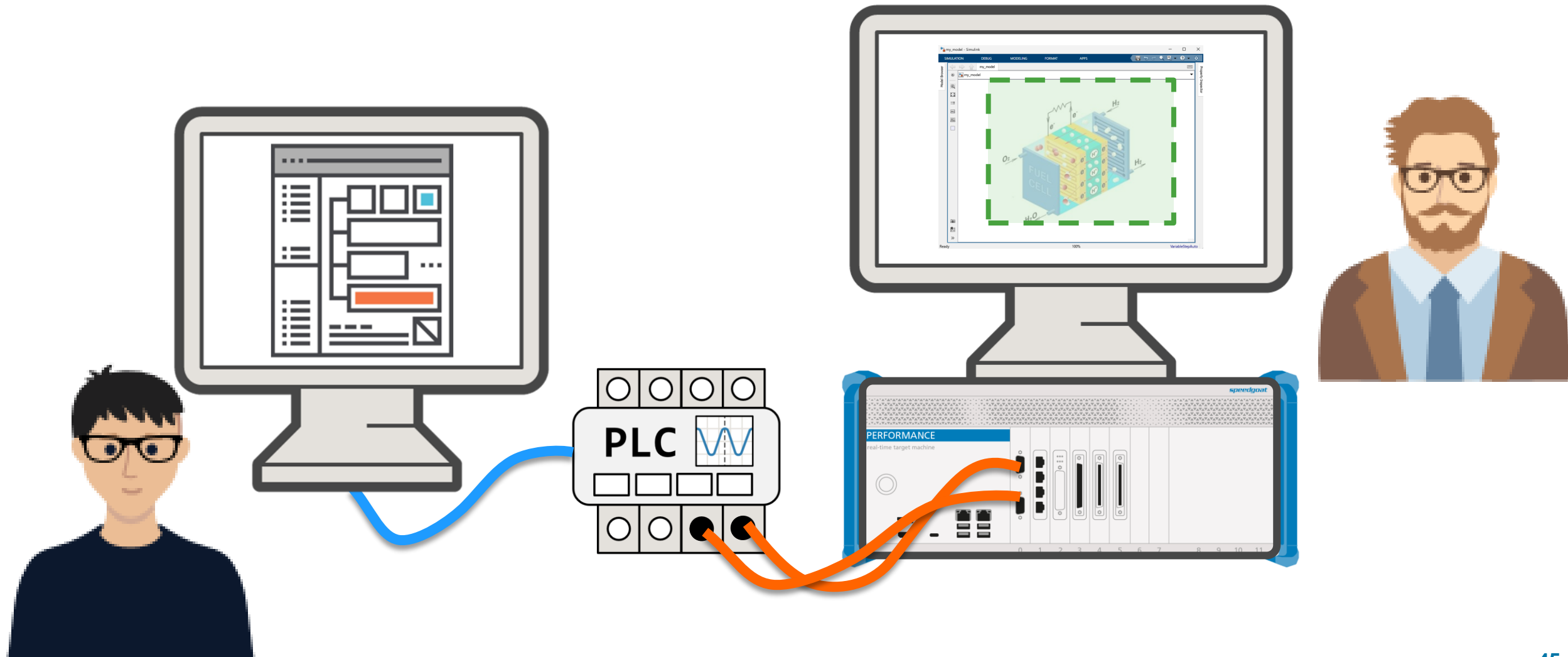
- Module setup: PWM generation
- Triggers: Triggers
- Input ports configuration: Input ports configuration
- PWM pattern is: Symmetric - PWM generation is centered around half the period
- PWM B output is: The complement of PWM A output
- Deadband duration vector [s]: [10e-9]
- Initial period vector [s]: pwmPeriod
- Initial frequency vector [Hz]: 25000
- Initial PWM A duty cycle vector: [0.0]
- Initial C-On vector [s]: [0.0]
- Initial C-Off vector [s]: [0.0]
- AB-output protection: Disabled: A and B can be high at the same moment
- ☐ Enable the second update at half of PWM period

Two orange arrows point from the text labels to the corresponding parts of the Simulink interface:

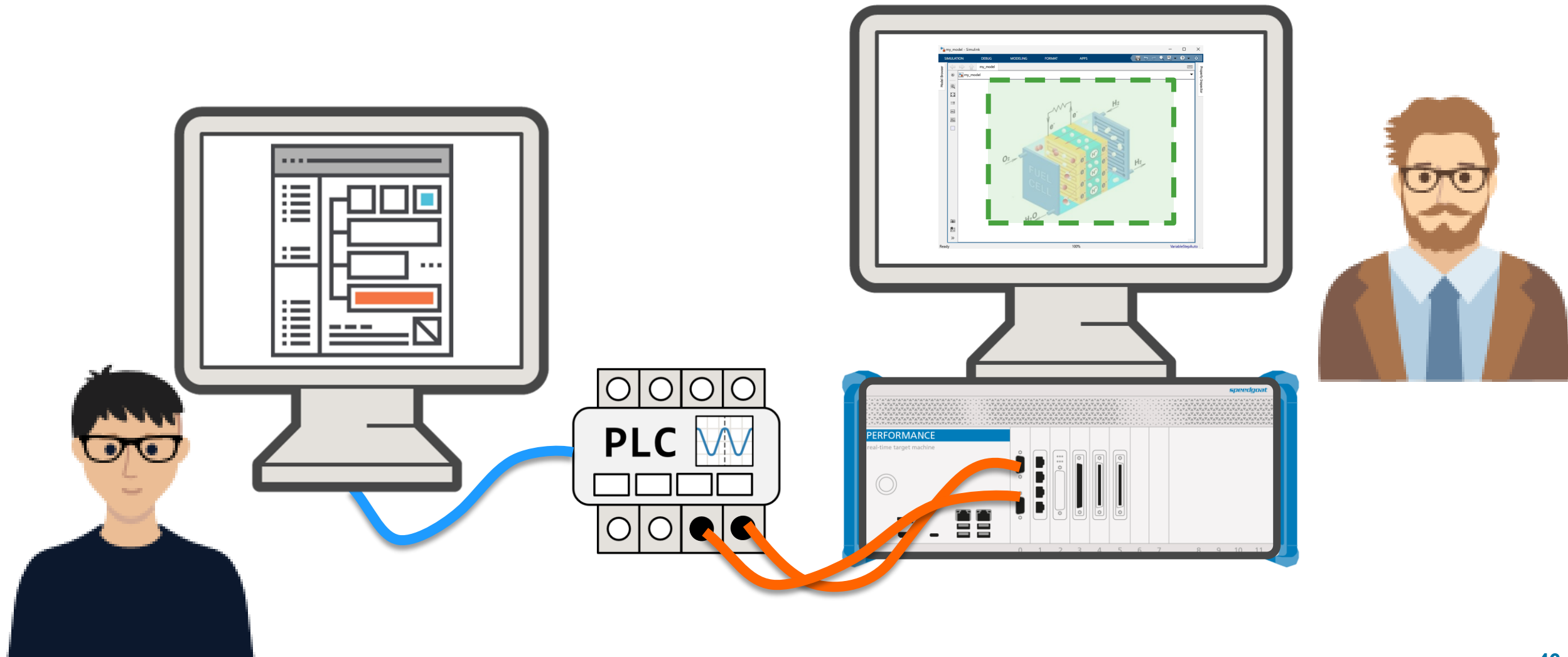
- Drag-and-drop I/O blocks** points to the Simulink Library Browser.
- Configure I/O parameters in Simulink** points to the 'Block Parameters: PWM generation (5)' dialog box.



# 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





# MATLAB EXPO

 FRANCE

# Thank you!



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