MATLAB EXPO 2019

Power Electronics Real-time HIL
Testing with FPGA Acceleration

Topics to be Covered

- Motivation for real-time with power electronics

- Capturing power electronics switching events utilizing FPGAs

- How to create a power electronics real-time simulation
  - Demo – Solar inverter

  - Automatically converting models for deployment to FPGAs (New feature 2018b)
    - How to convert circuit model to FPGA code (HDL)

  - Perform all tasks from a single environment: Simulink
    - Biggest selling point of this workflow

What is Our Goal?

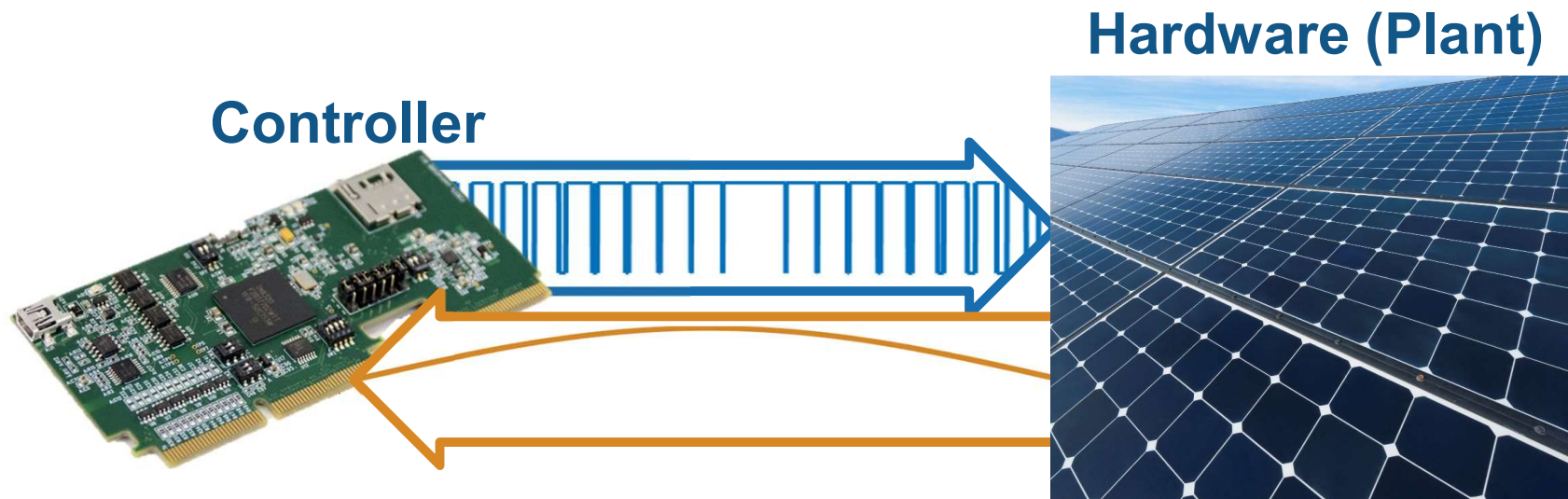- Primary goal is to design power electronics hardware and controllers
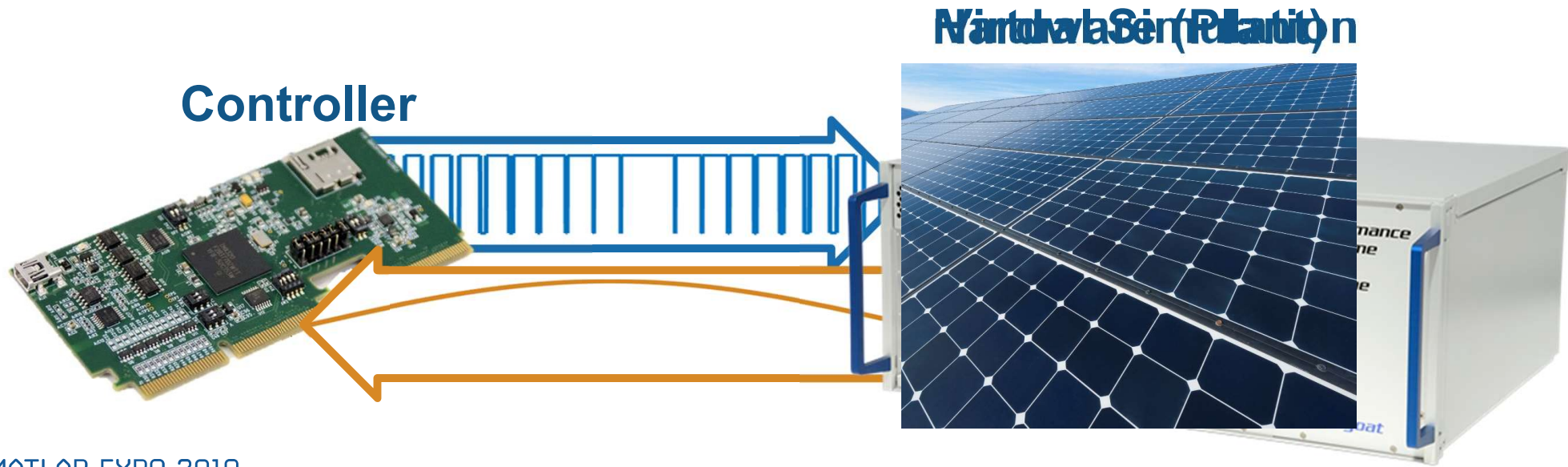
Hardware (Plant)

Controller

What is Our Goal?

- Primary goal is to design power electronics hardware and controllers
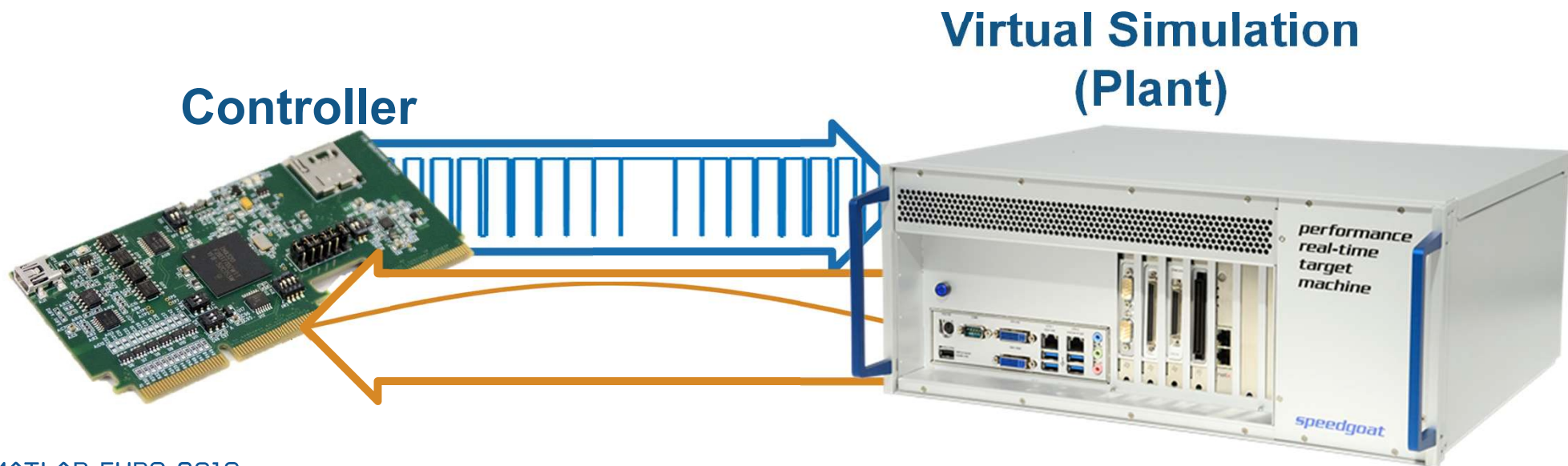 - Hardware in the loop (HIL) testing can improve this process

Hardware (Plant)

Controller

What is Hardware in the Loop (HIL) Testing

- HIL replaces the power electronics hardware with a virtual simulation

**Controller**

Virtual Sim (Plant)

What is Hardware in the Loop (HIL) Testing

- HIL replaces the power electronics hardware with a virtual simulation
  - Controller can operate as if in the real system

Virtual Simulation (Plant)

Controller

Advantages of Hardware in the Loop (HIL) Testing

- Can replace prototypes or production hardware with a real-time system
- Easier to automate testing and test fault conditions
- Safer than most power electronics hardware
- Start many design/test tasks earlier

Controller

Virtual Simulation (Plant)

performance real-time target machine

speedgoat
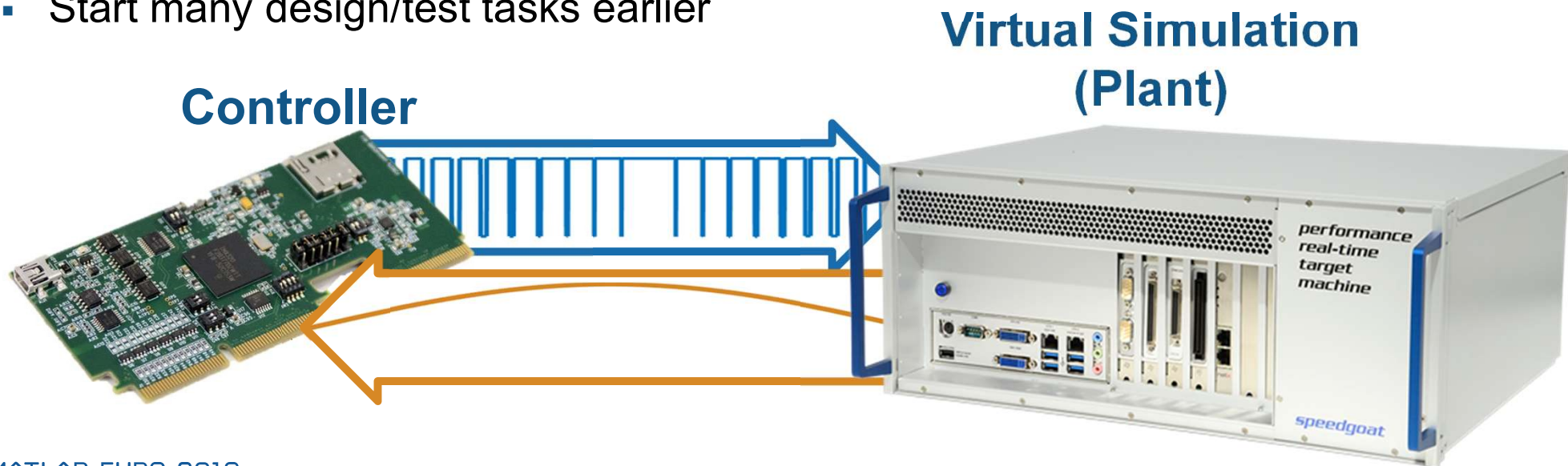
Why are FPGAs Important for Real-time

- Certain issues make running a model real-time challenging
  - Minimum time step
  - Model complexity
  - Specialized solvers

Why is are FPGAs Important for Real-time

- It is all about time step
  - Thermal – seconds
  - Mechanical – milliseconds
  - Power Systems – sub-milliseconds
  - Power Electronics – microseconds
  - Radar – nanoseconds

- Typical real-time CPU based solutions run in the sub-millisecond range

- FPGA based solutions run in the microsecond range
  - bordering sub-microsecond for specific applications

The Need for Small Time Step Simulations

- High sample rates (small time steps) are required to capture fast transients in systems like power electronics

Resolution: microseconds

Resolution: milliseconds

Resolution: seconds
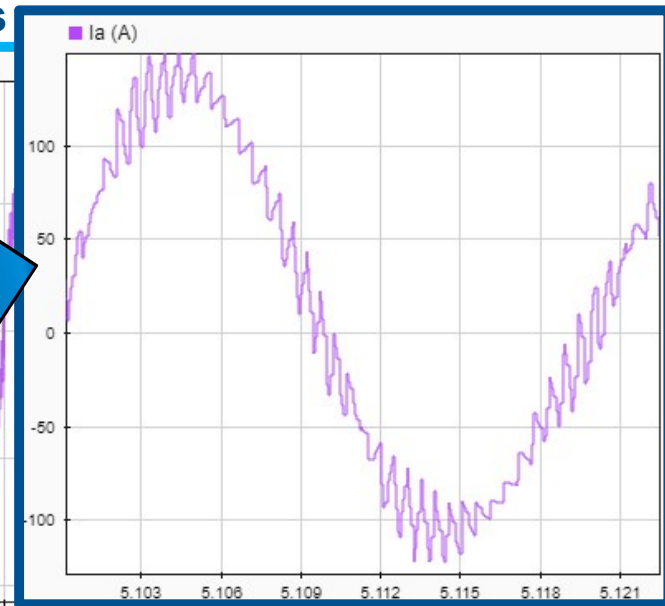
Path to FPGA Accelerated Real-time: Simscape

1. ## Create a model of the system
   - Often called 'Desktop Simulation'
   - Can combine Simscape with Simulink

2. ## Convert model to HDL
   - Allows model to run on an FPGA
   - Utilize Simscape to HDL Advisor

3. ## Program real-time machine with custom bitstream
   - Bitstream is the program on the FPGA
   - Combine with standard Simulink model on a CPU
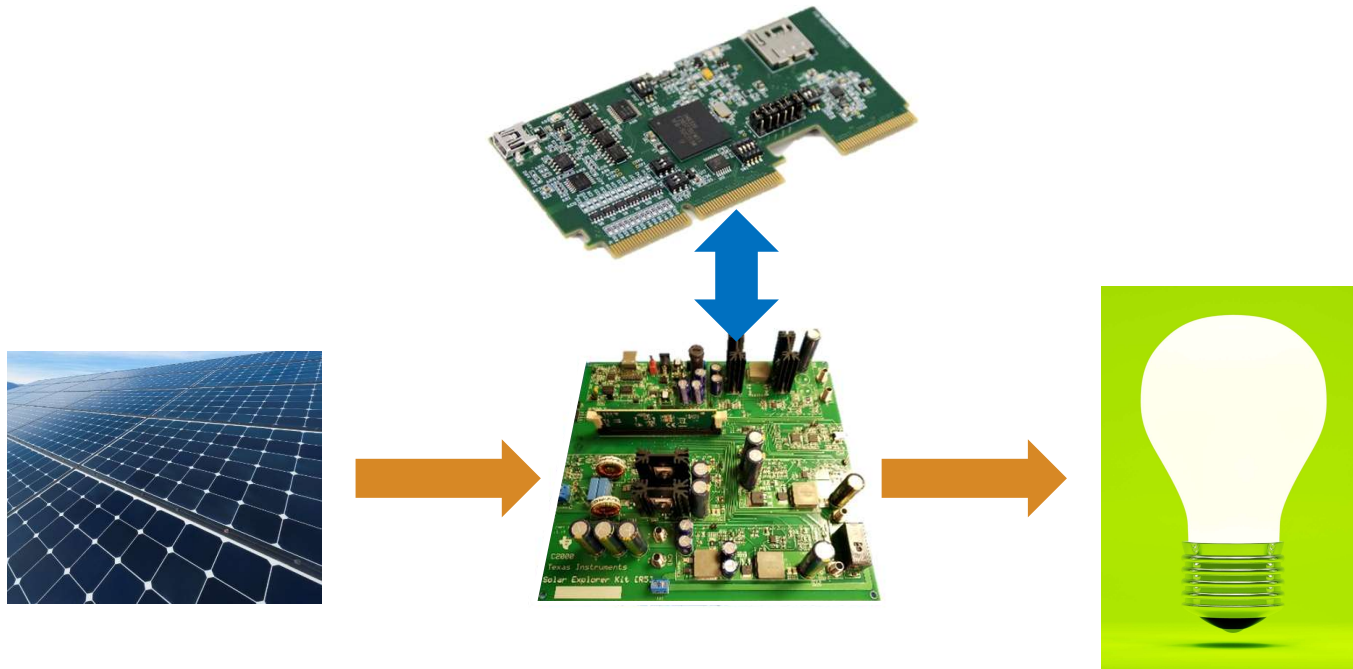
MathWorks Supports Many Power Electronics Applications
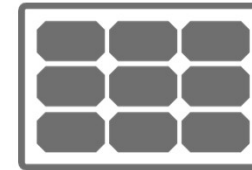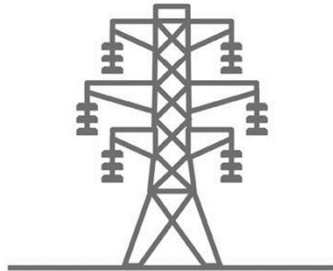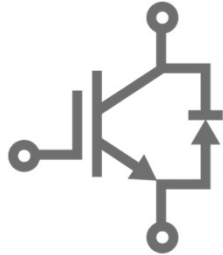
Solar Inverter for Real-time Testing
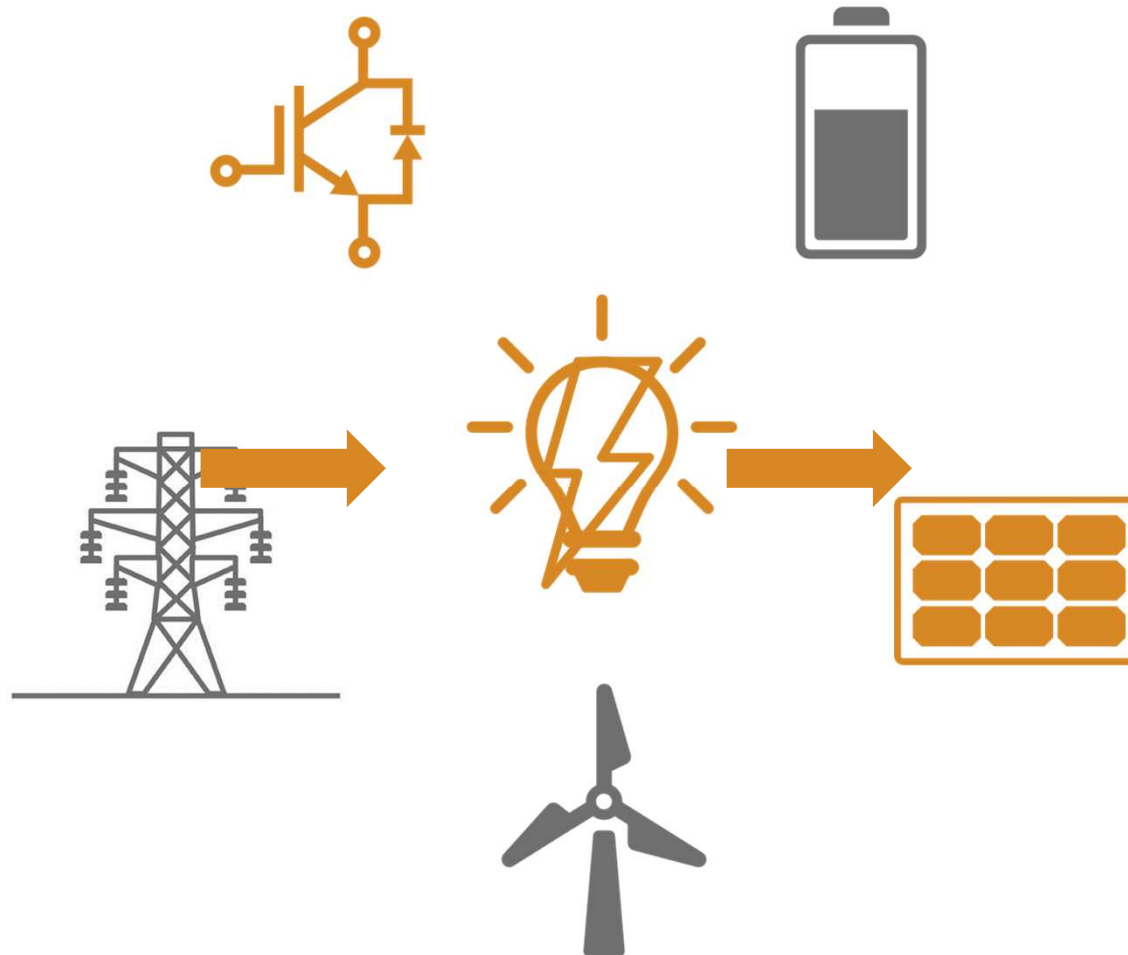
Solar Inverter for Real-time Testing
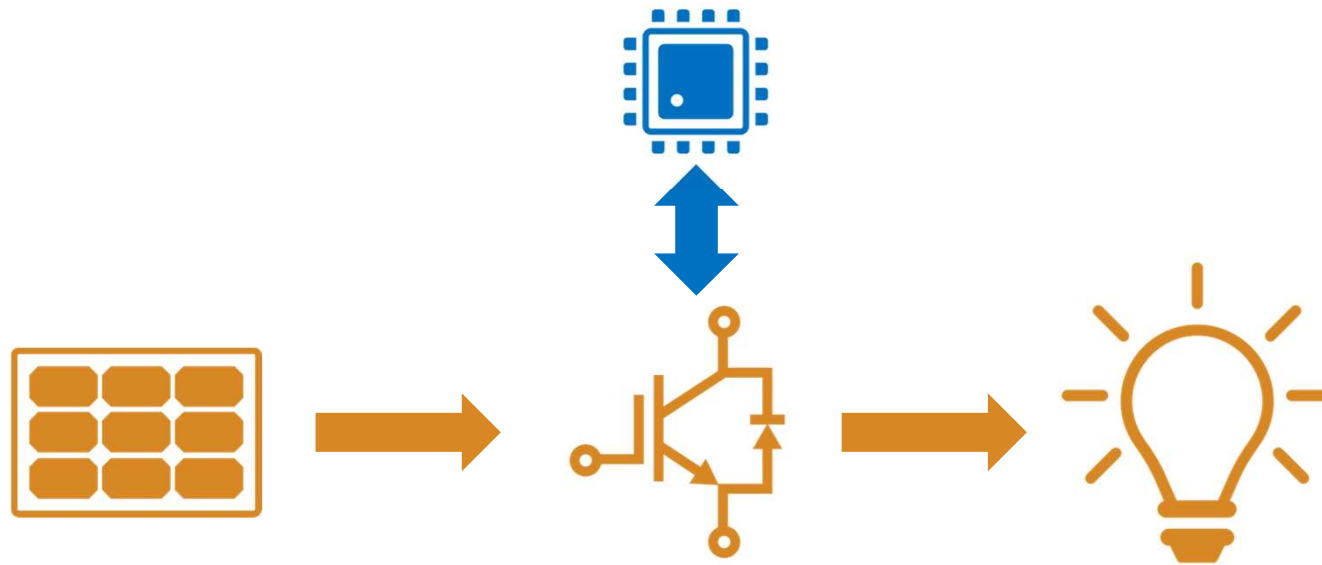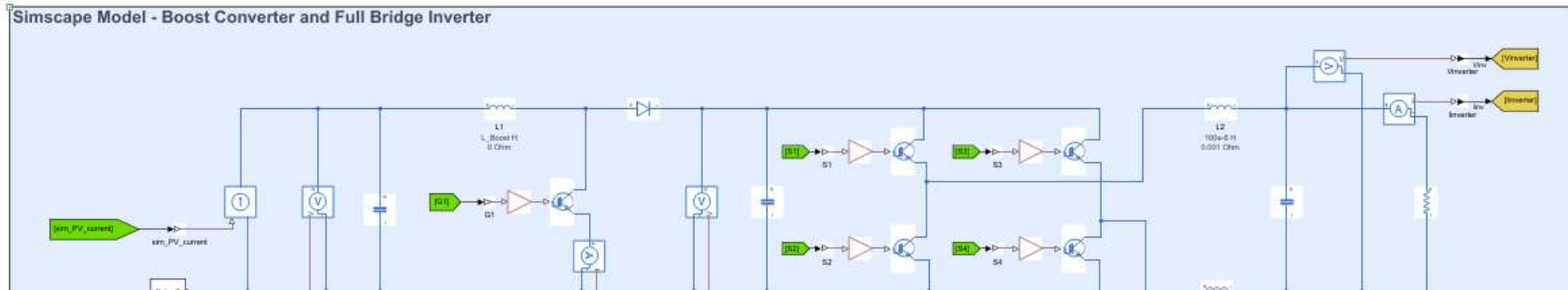
Solar Inverter for Real-time Testing
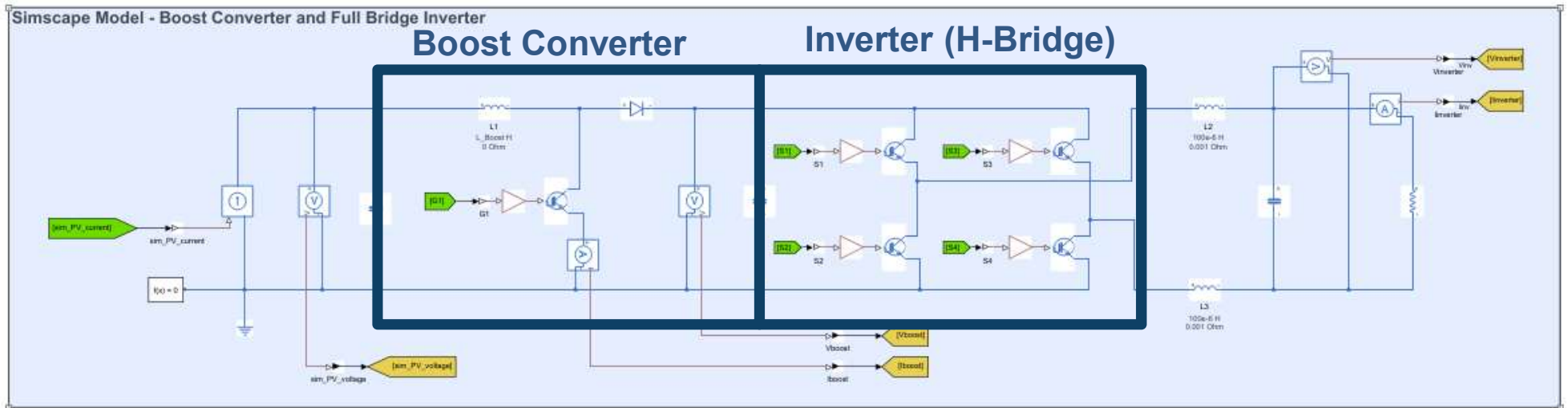
Step 1: Create a Model (Desktop Simulation)
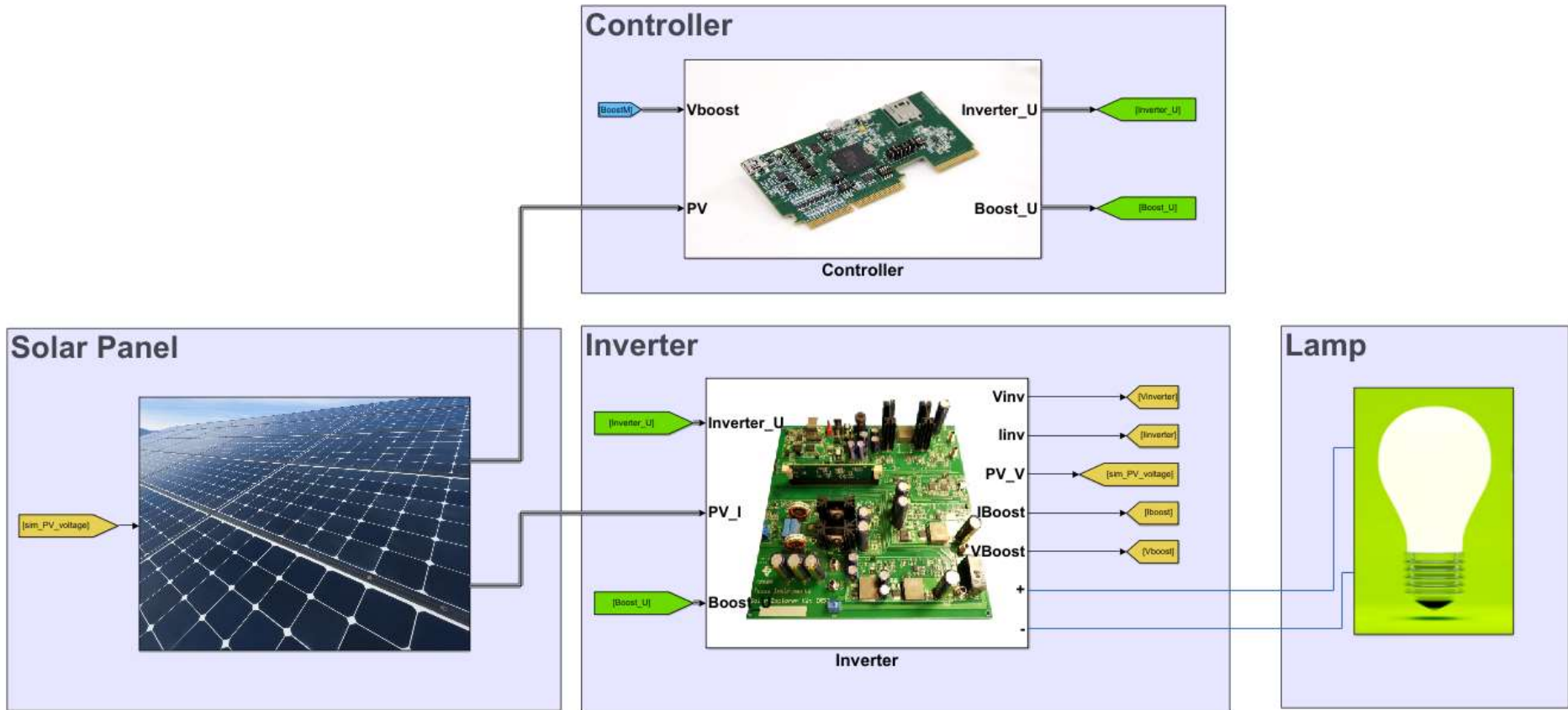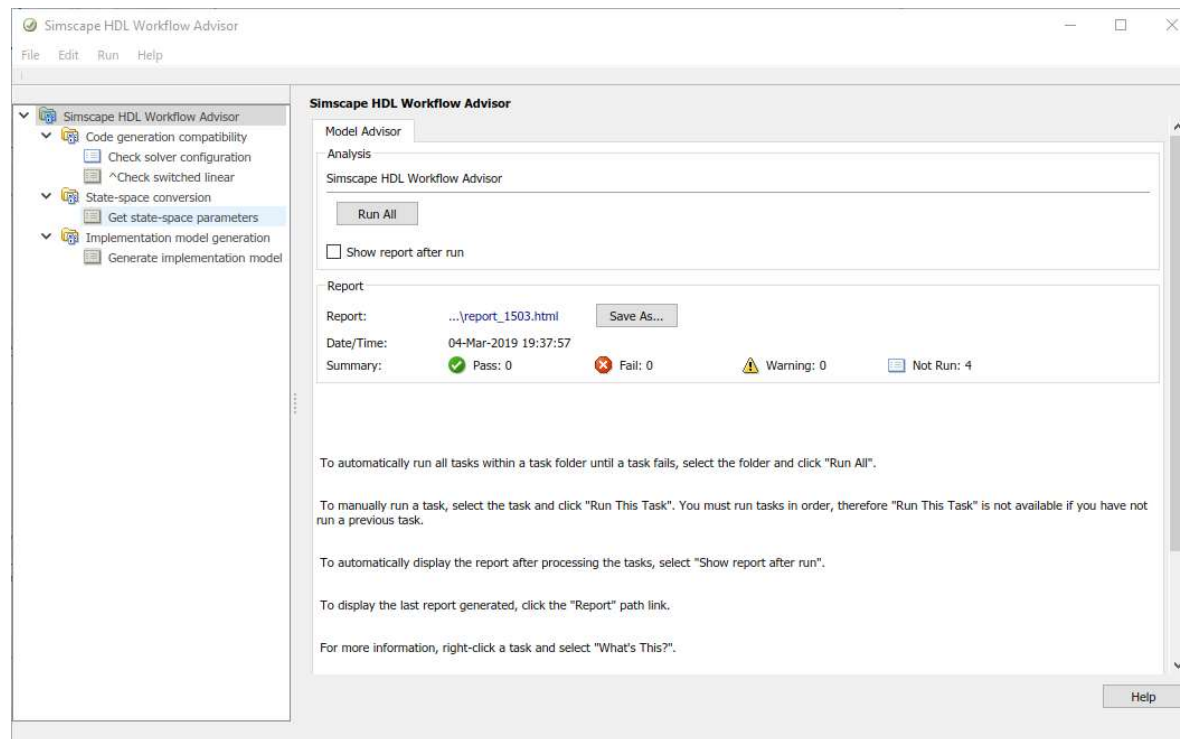
Inverter and Boost Converter Model

Inverter and Boost Converter Model

Simscape Model - Boost Converter and Full Bridge Inverter

Boost Converter   **Inverter (H-Bridge)**

**Need to convert continuous models to discrete
models appropriate for an FPGA**
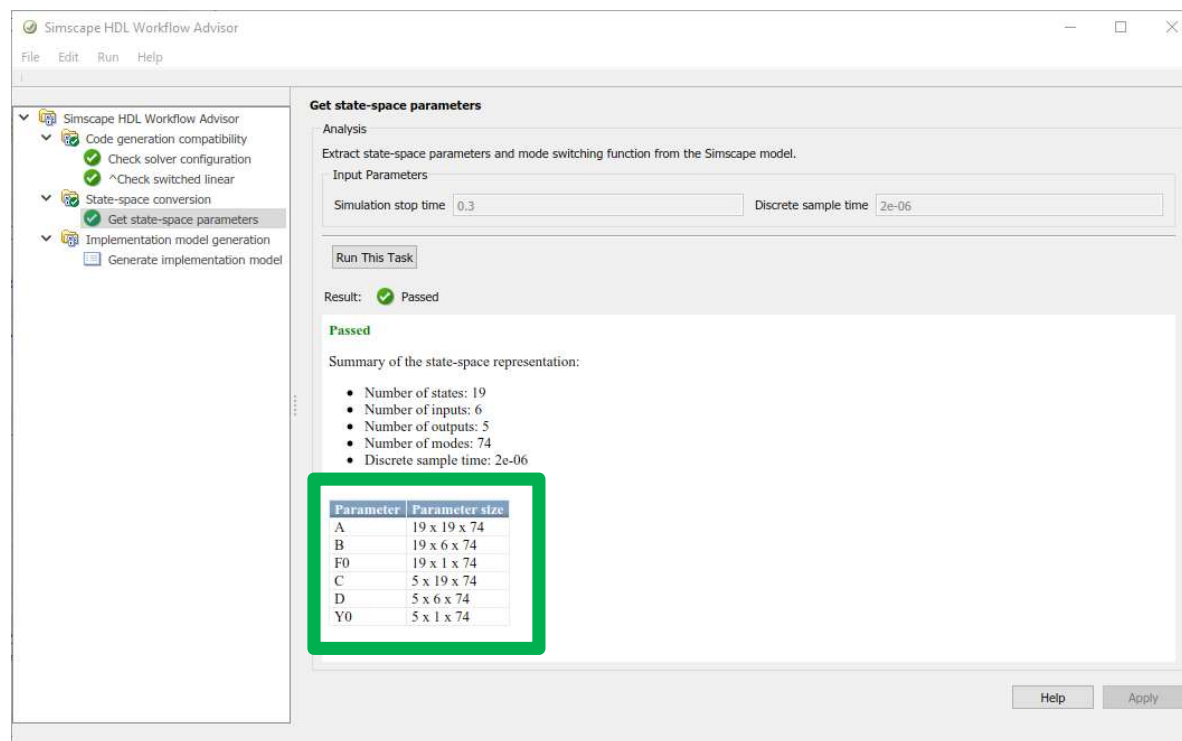
Convert to HDL: Simscape HDL Workflow Advisor
New Feature 2018b

- Run 'sschdladvisor' on model

Extract State Space Parameters (Linearize the System)

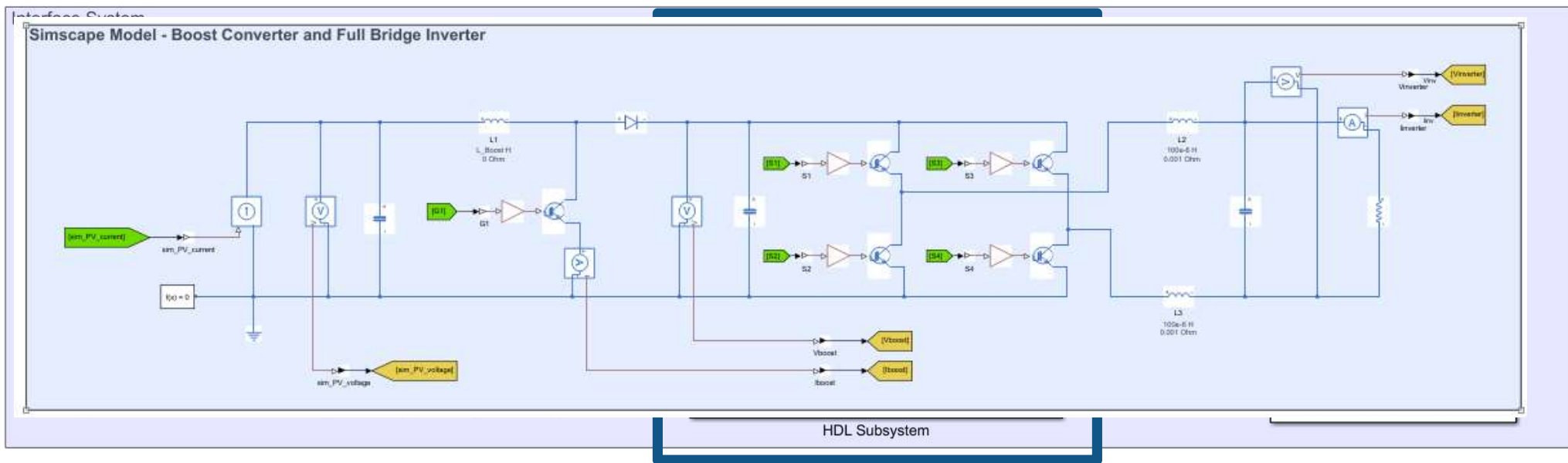▪ Simulation must contain all relevant switching states

Simscape HDL Workflow Advisor

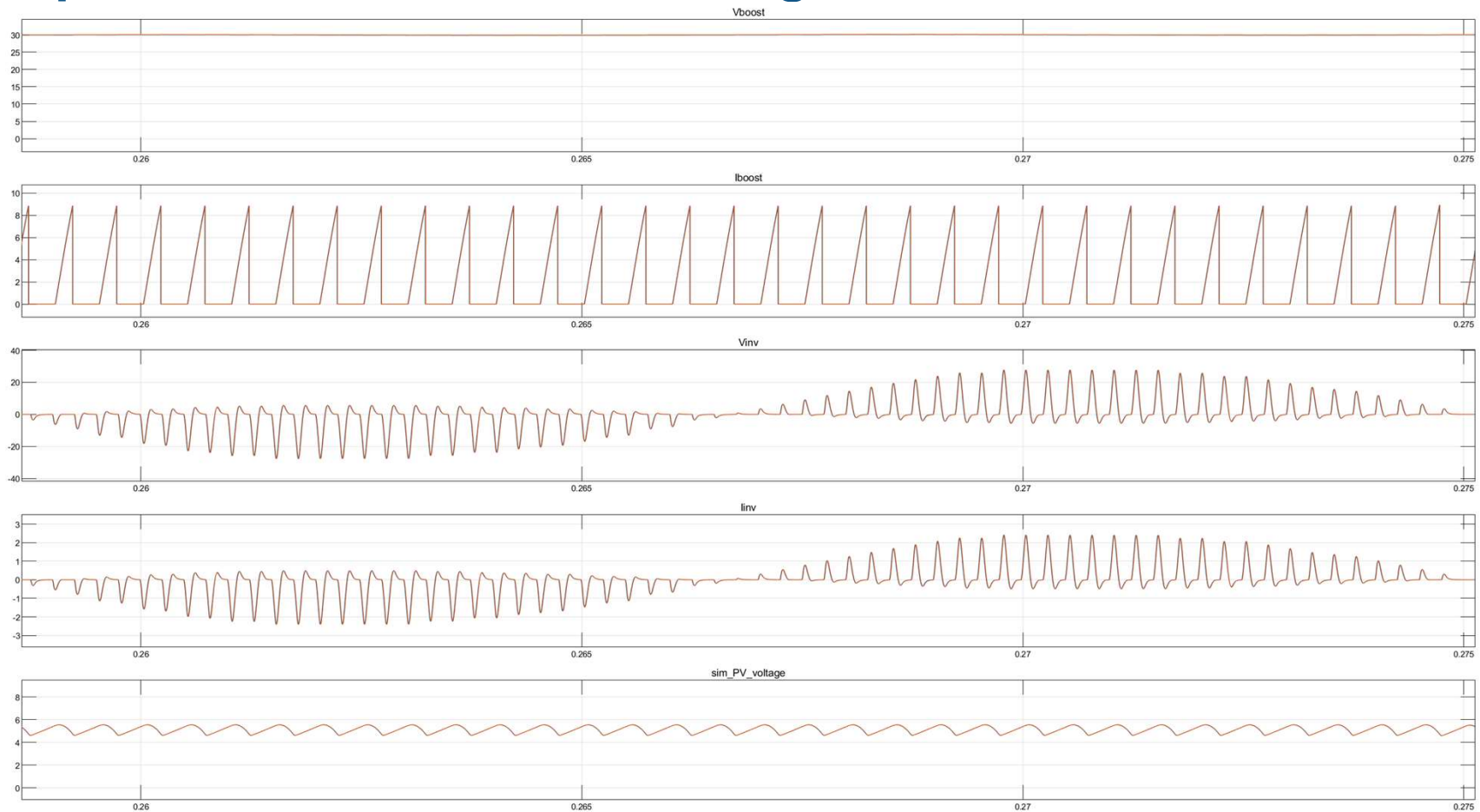- Choose smallest number of solver iterations possible (usually 3-5)
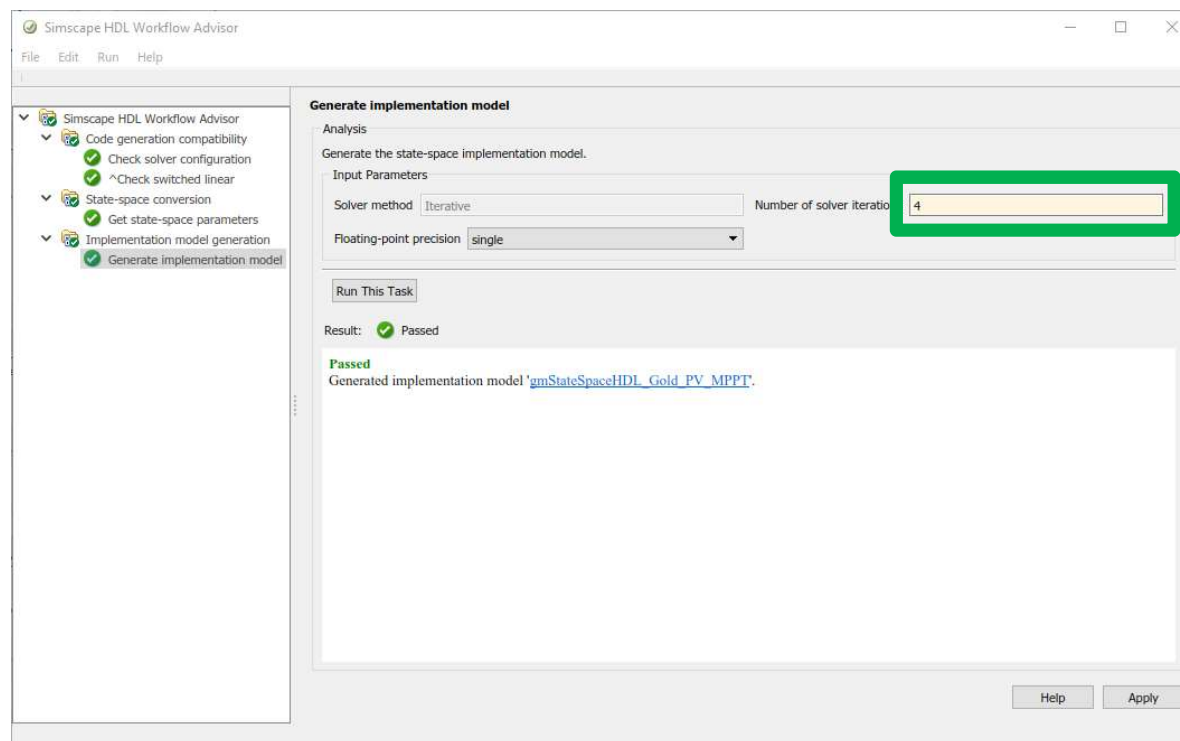
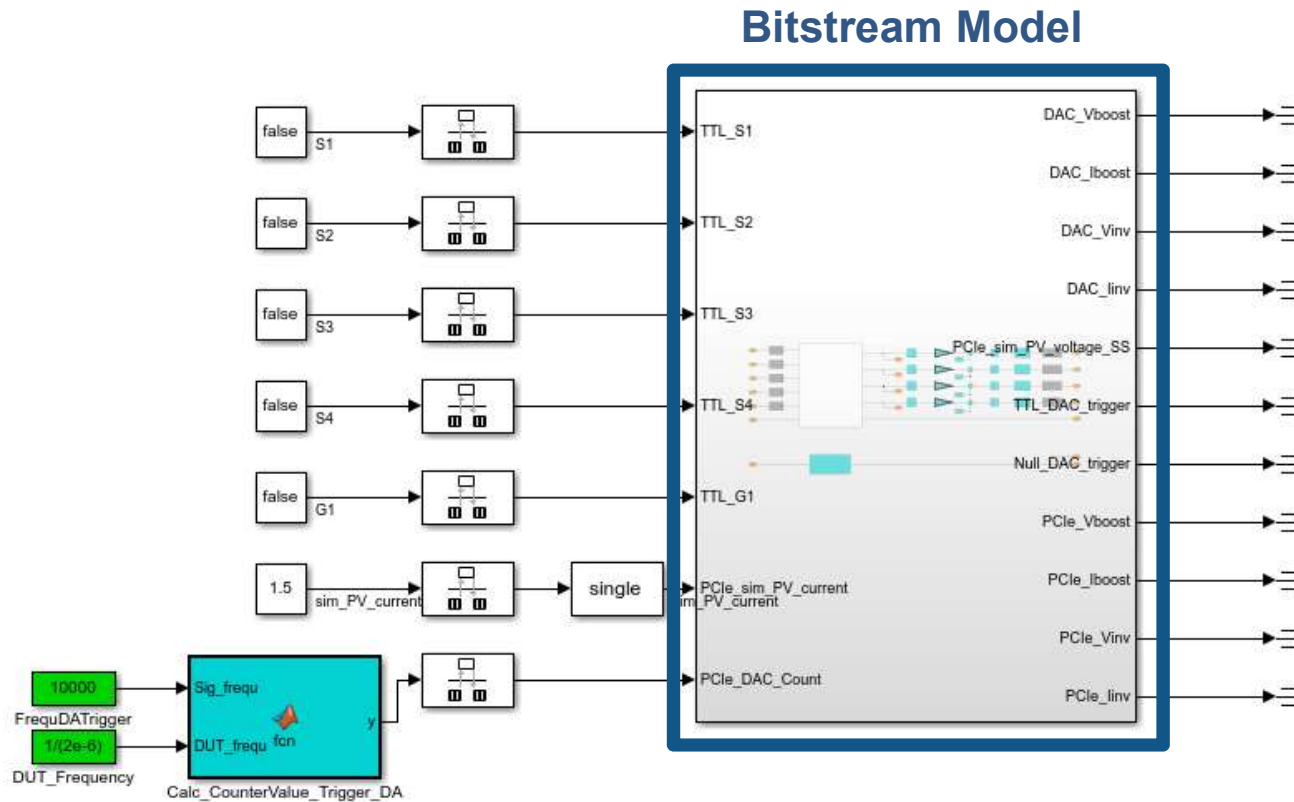# Implementation Model

Replaces Simscape with State-space
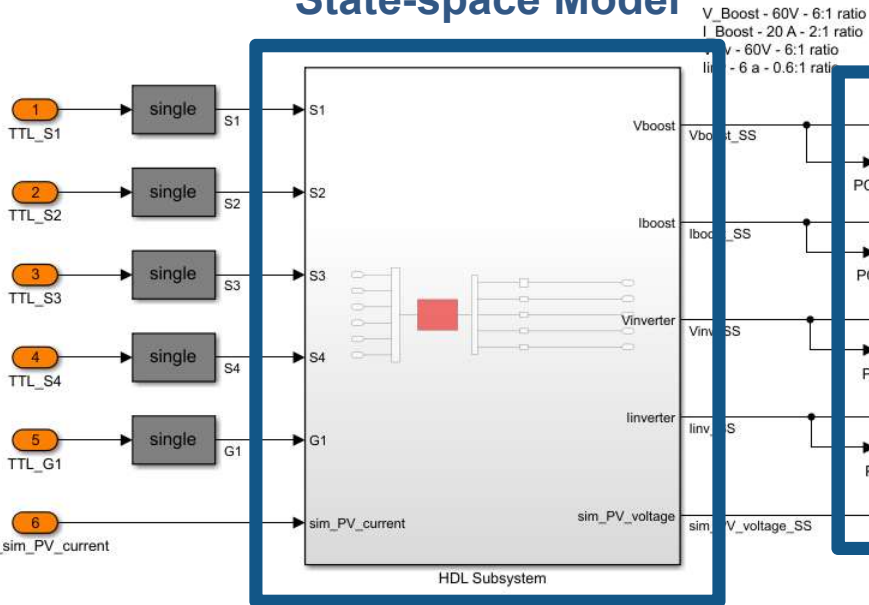
Compare Generated Model to Original
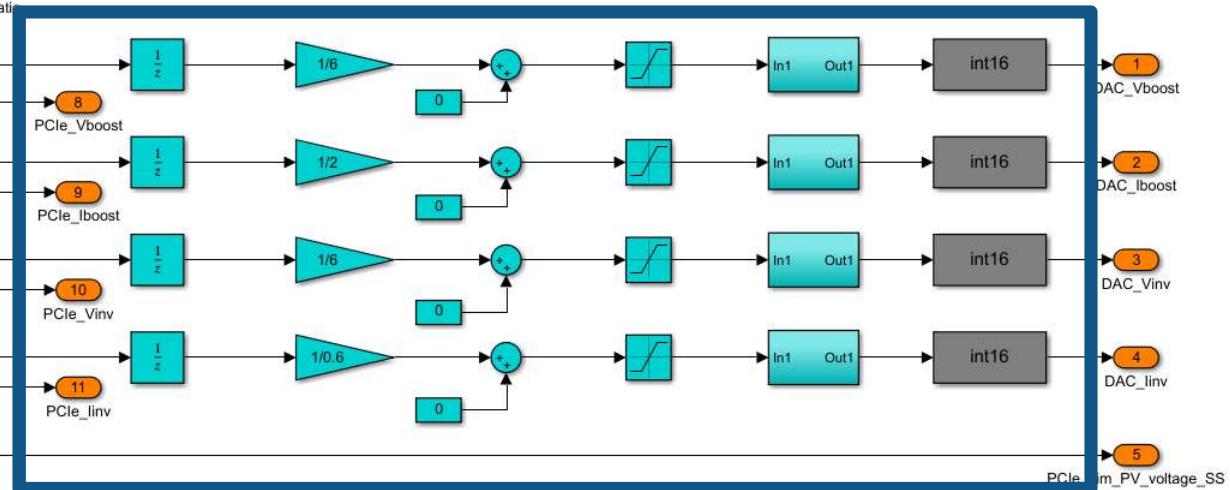
Create Custom Bitstream for Real-time FPGA

Bitstream Model
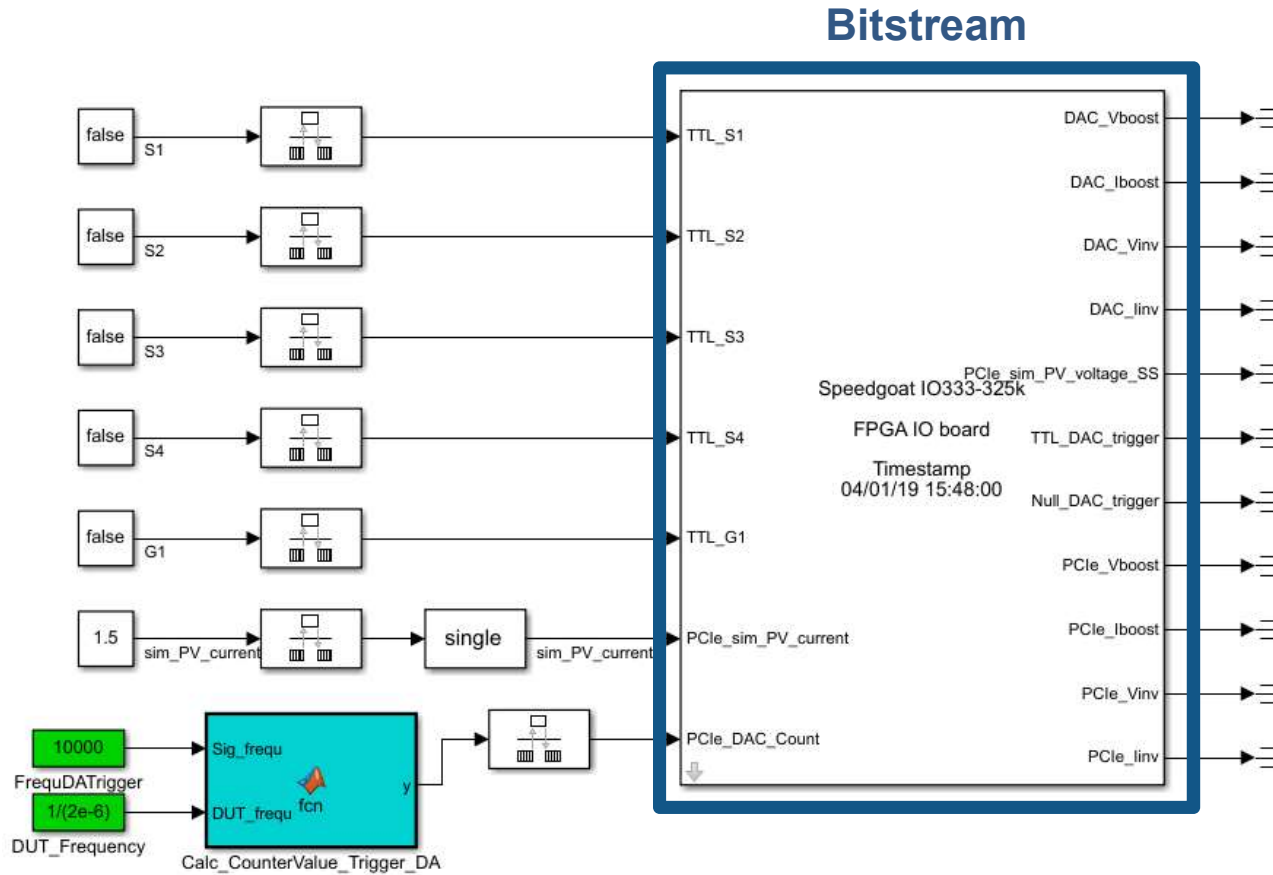
Create Custom Bitstream for Real-time FPGA

State-space Model

Analog Peripheral Scaling
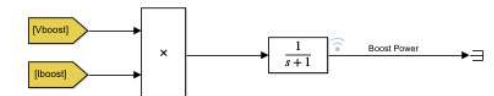
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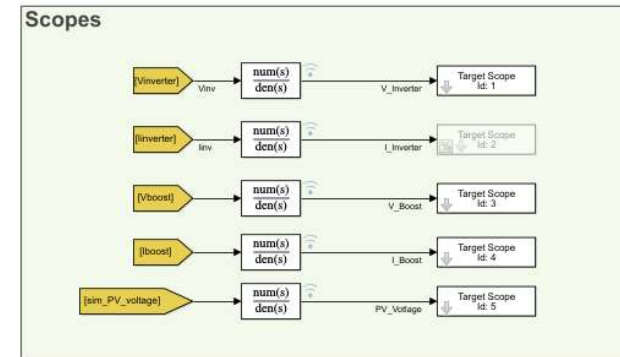
![MathWorks logo]

Combine with Simulink Model

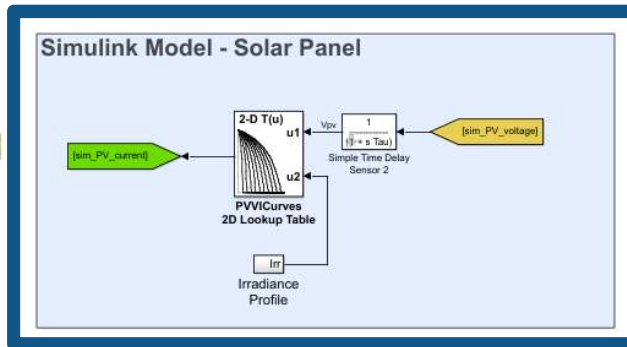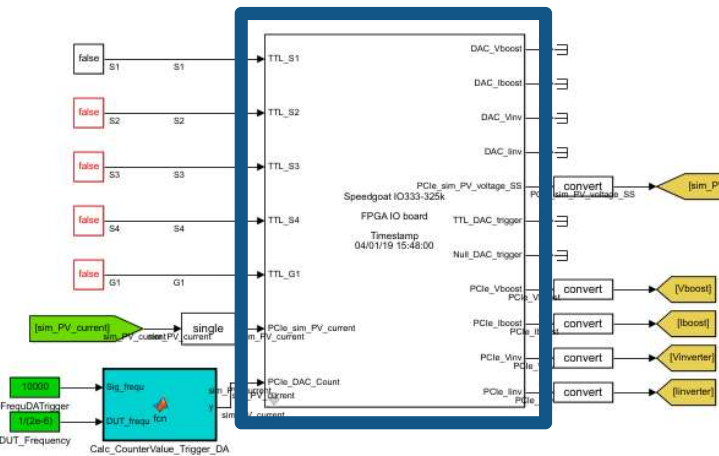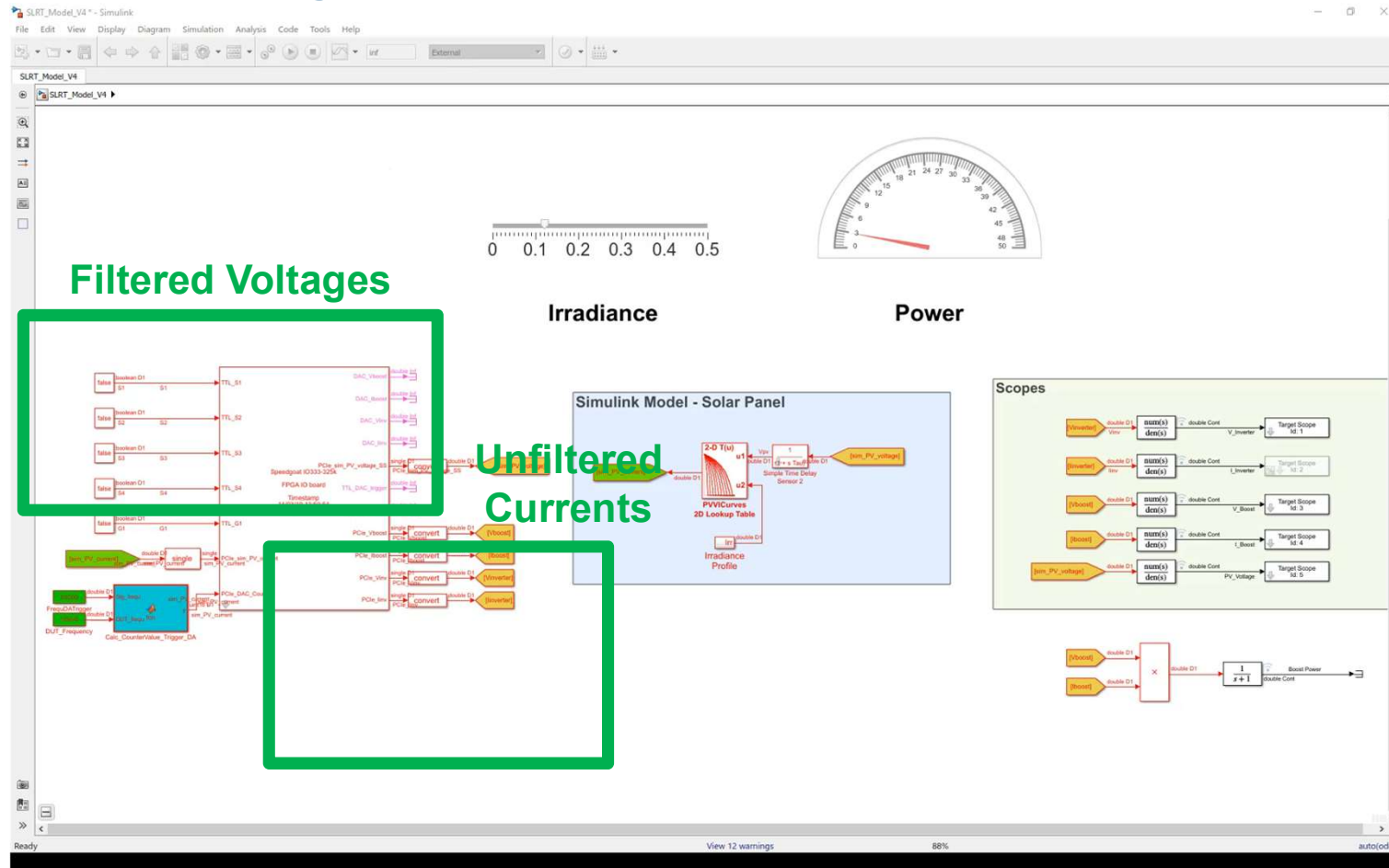**Dashboard Real-time Interface**
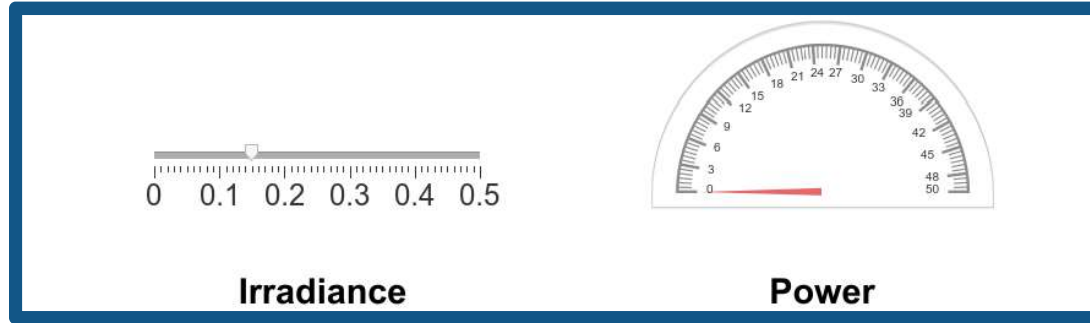
Bitstream

CPU Based Model

Demo Recording

Scope Screenshot

FPGA captures the switching transients

**Inverter Current
(LC Filter)**

**Boost Current
(DC Cap)**

Demo Configuration Details

- Controller – C2000

- Real-time System – Speedgoat Baseline-M
  - IO333 06-21 Kintext 7, 325k FPGA card expansion

2018b Capabilities - Kintex 7 325K

- Works specifically for switched linear systems (piecewise linear)
  - Supports multiple domains
  - Can connect to Simulink motor models

- Ideal for 2-6 switching components per converter
  - Can link multiple converters for larger systems

- Typical systems run at 2 to 5 us
  - Simple systems can be faster than 1 us

Conclusions

- Real-time greatly improves embedded control design

- FPGAs are important for real-time simulation of power electronics

- Embedded control design and real-time testing can all be done in the same environment…

Simulink!