

# 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

### Controller

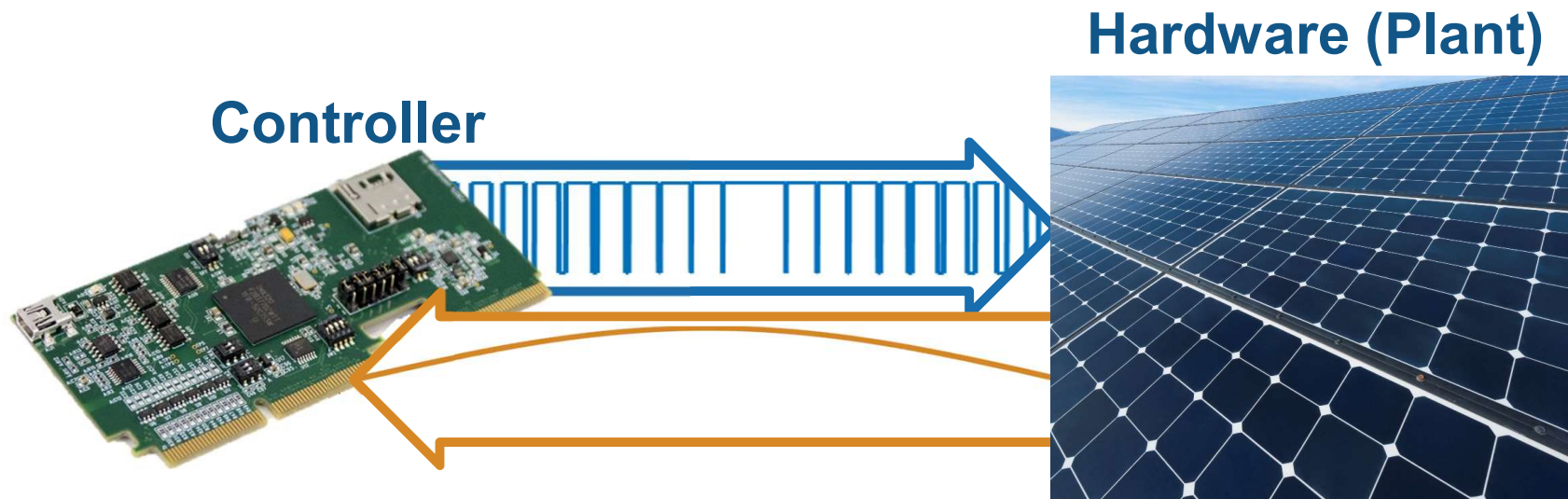


### Hardware (Plant)



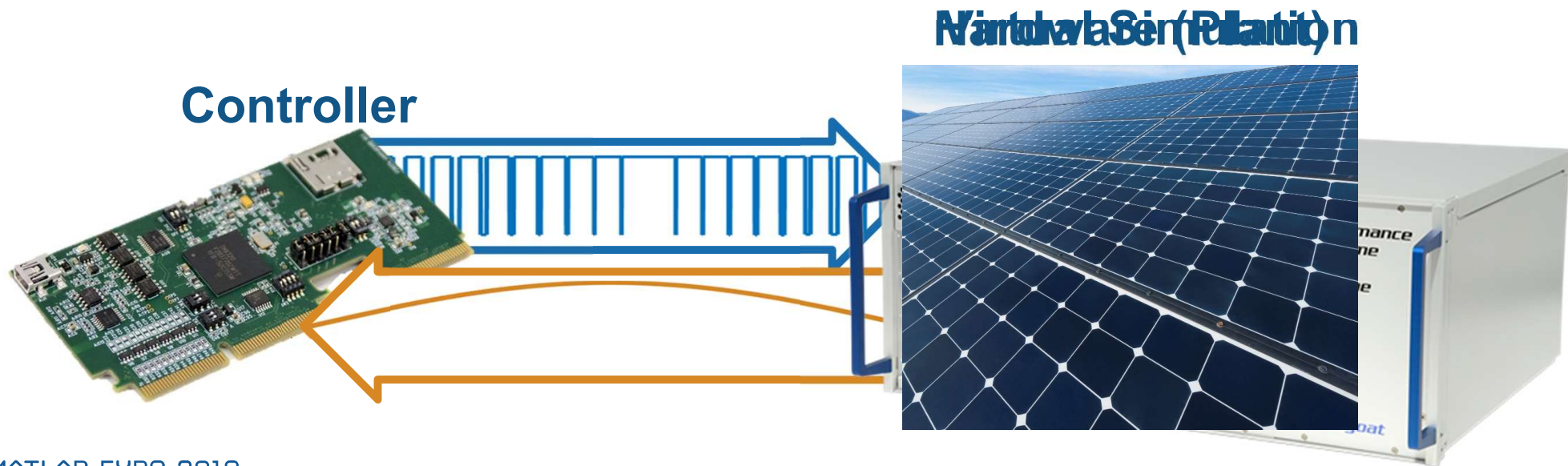
## What is Our Goal?

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



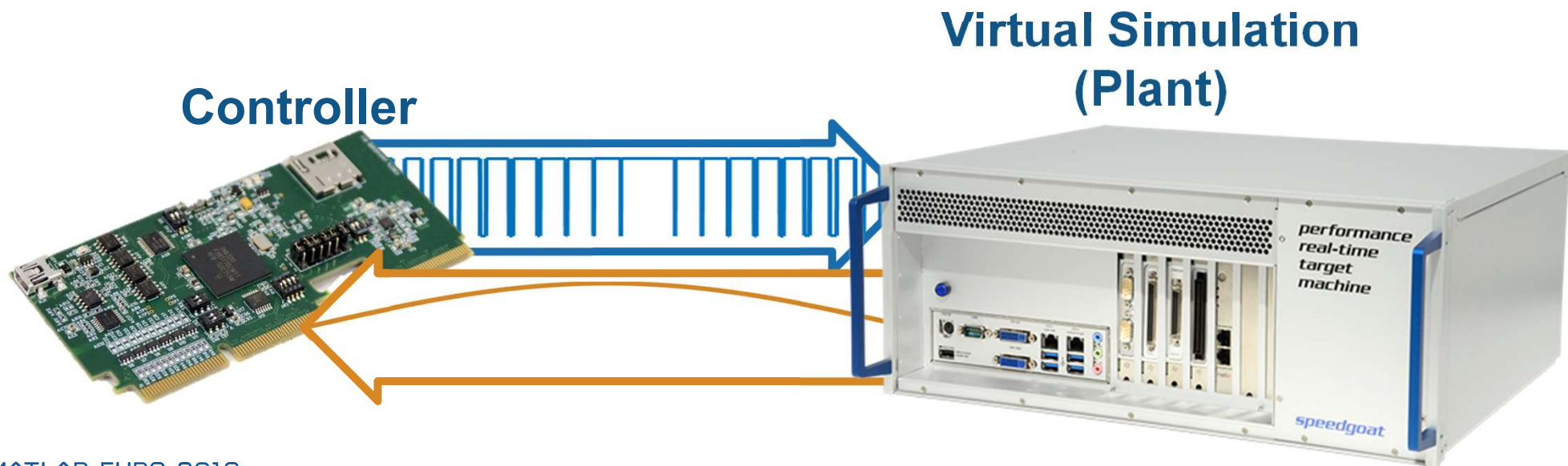
## What is Hardware in the Loop (HIL) Testing

- HIL replaces the power electronics hardware with a virtual simulation



## What is Hardware in the Loop (HIL) Testing

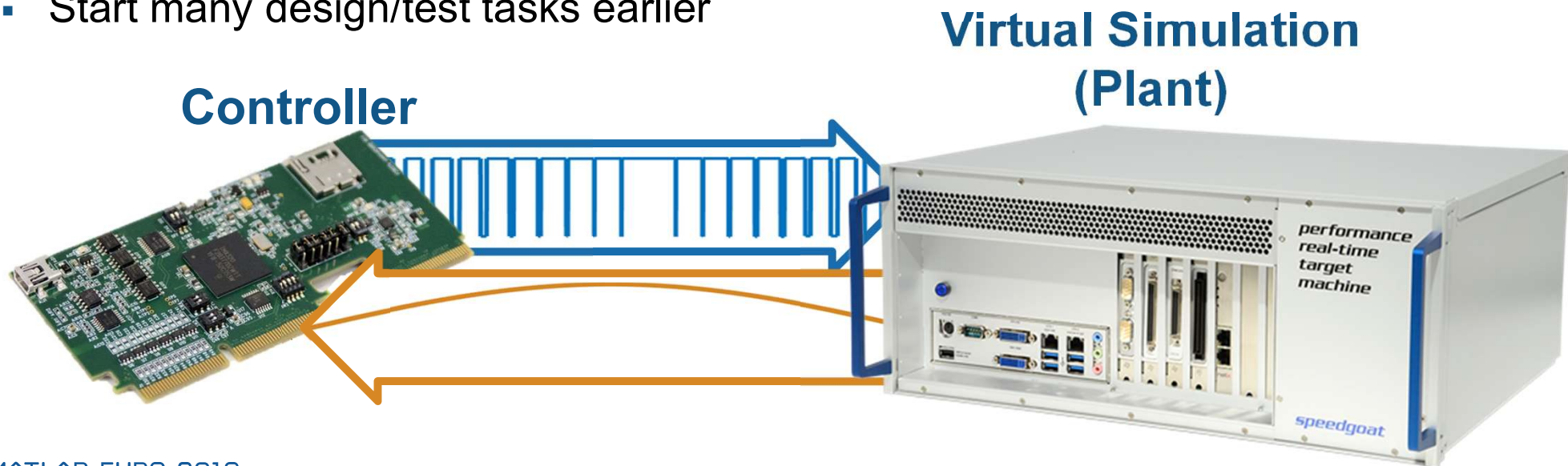
- HIL replaces the power electronics hardware with a virtual simulation
  - Controller can operate as if in the real system





## 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



## Why are FPGAs Important for Real-time

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



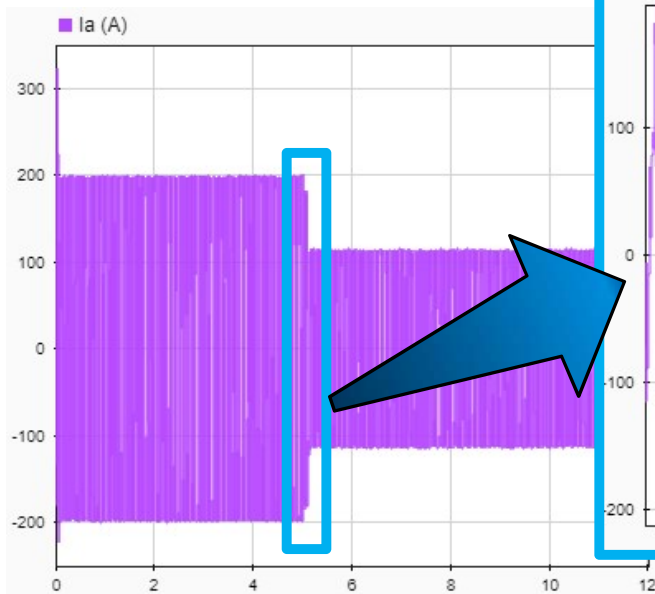
## Why are FPGAs Important for Real-time

- 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

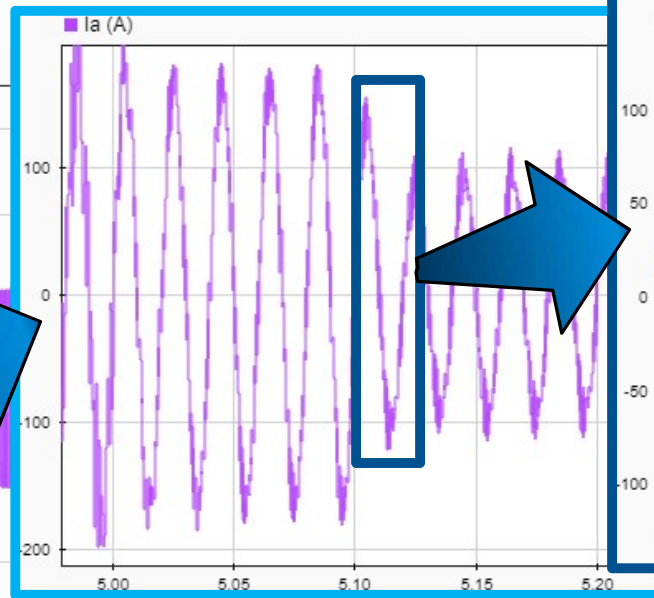
# The Need for Small Time Step Simulations

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

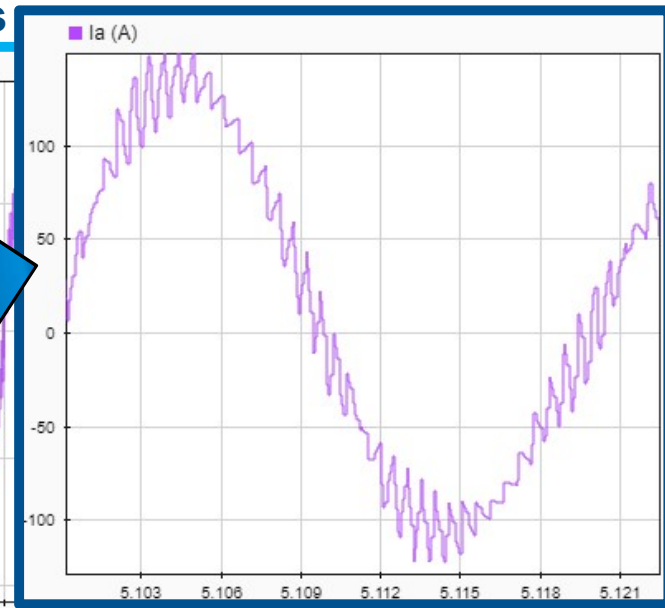
**Resolution: seconds**



**Resolution: milliseconds**



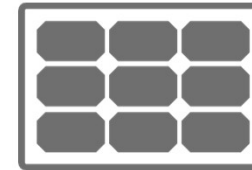
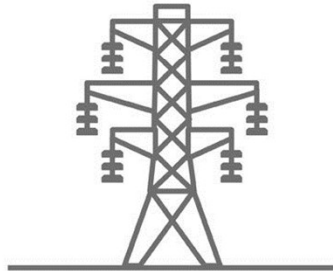
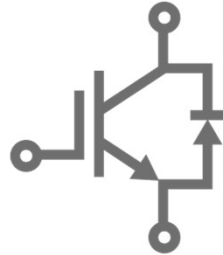
**Resolution: microseconds**



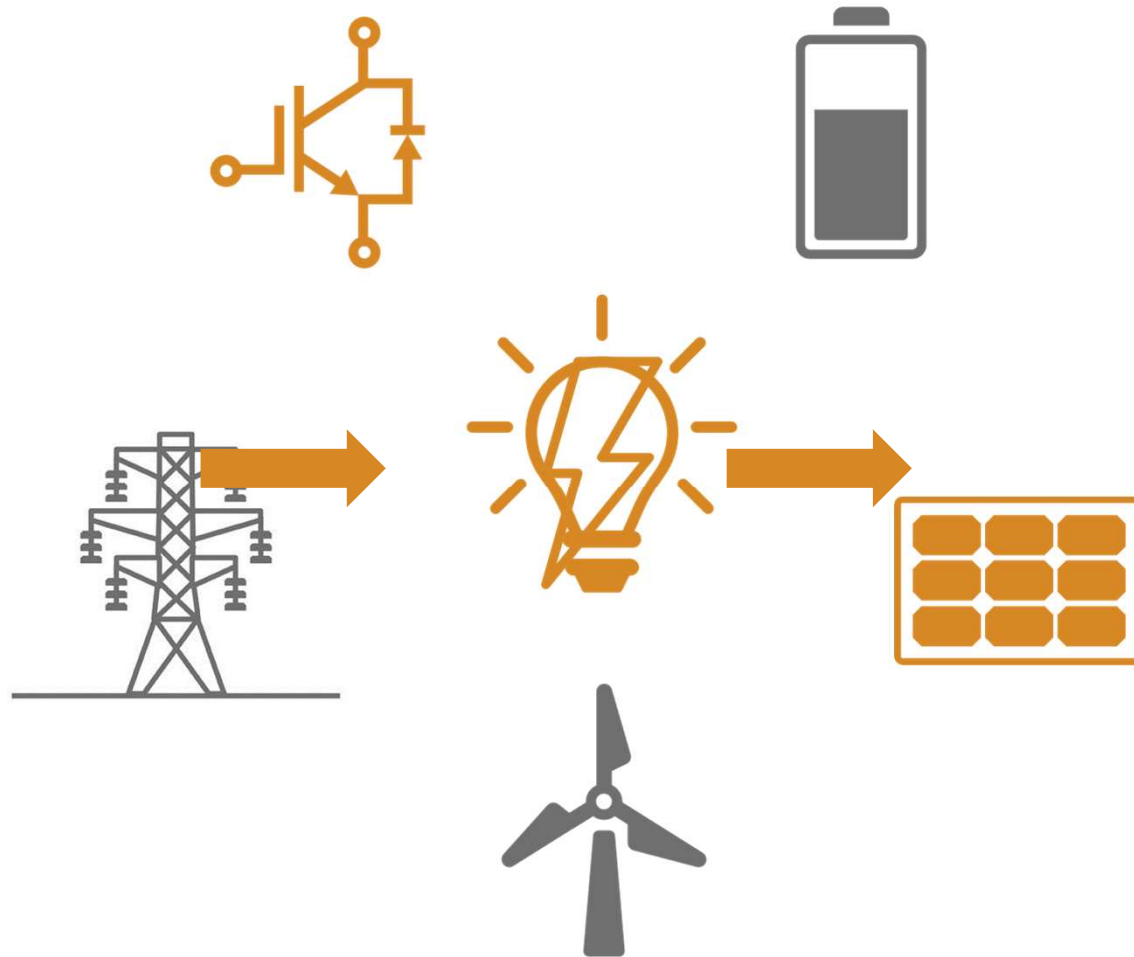
## Path to FPGA Accelerated Real-time: Simscape

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

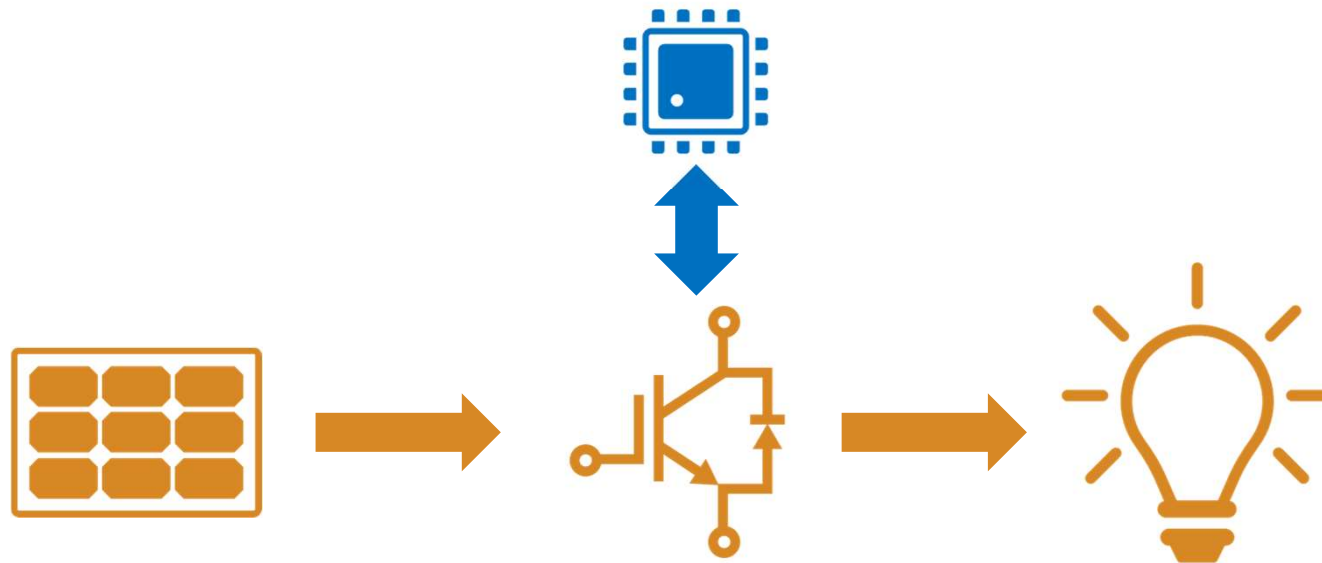
# MathWorks Supports Many Power Electronics Applications



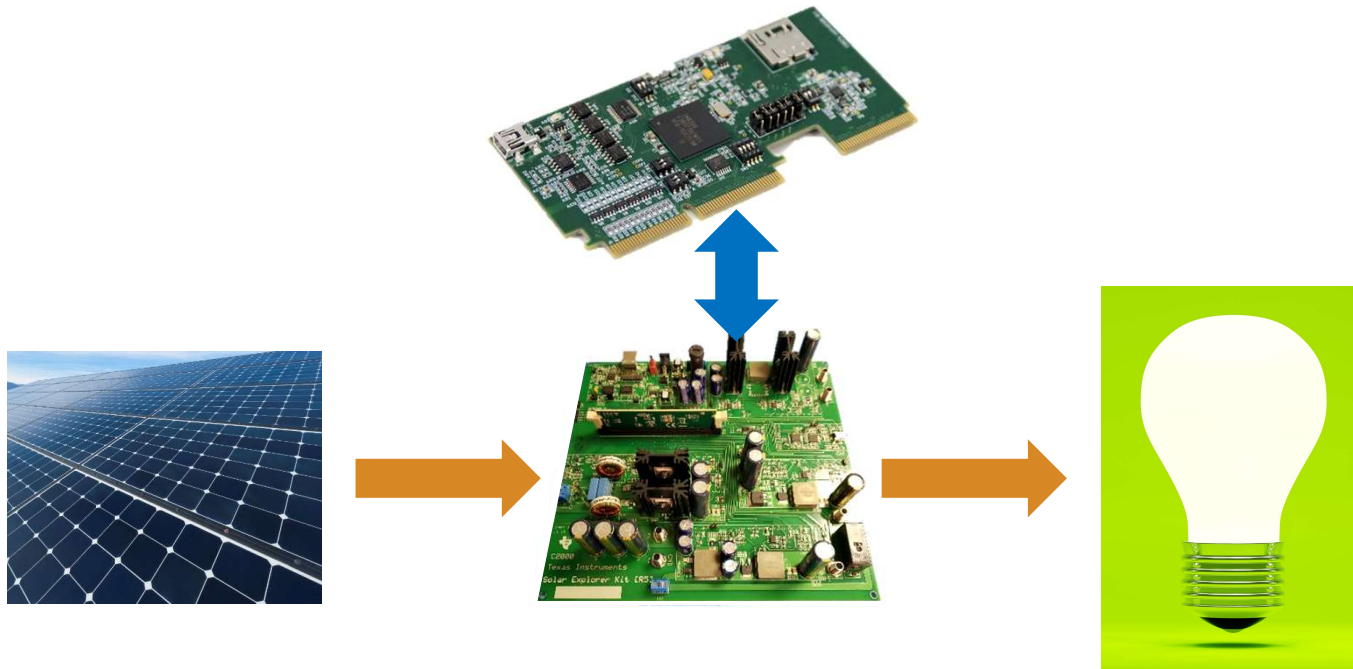
# Solar Inverter for Real-time Testing



## Solar Inverter for Real-time Testing

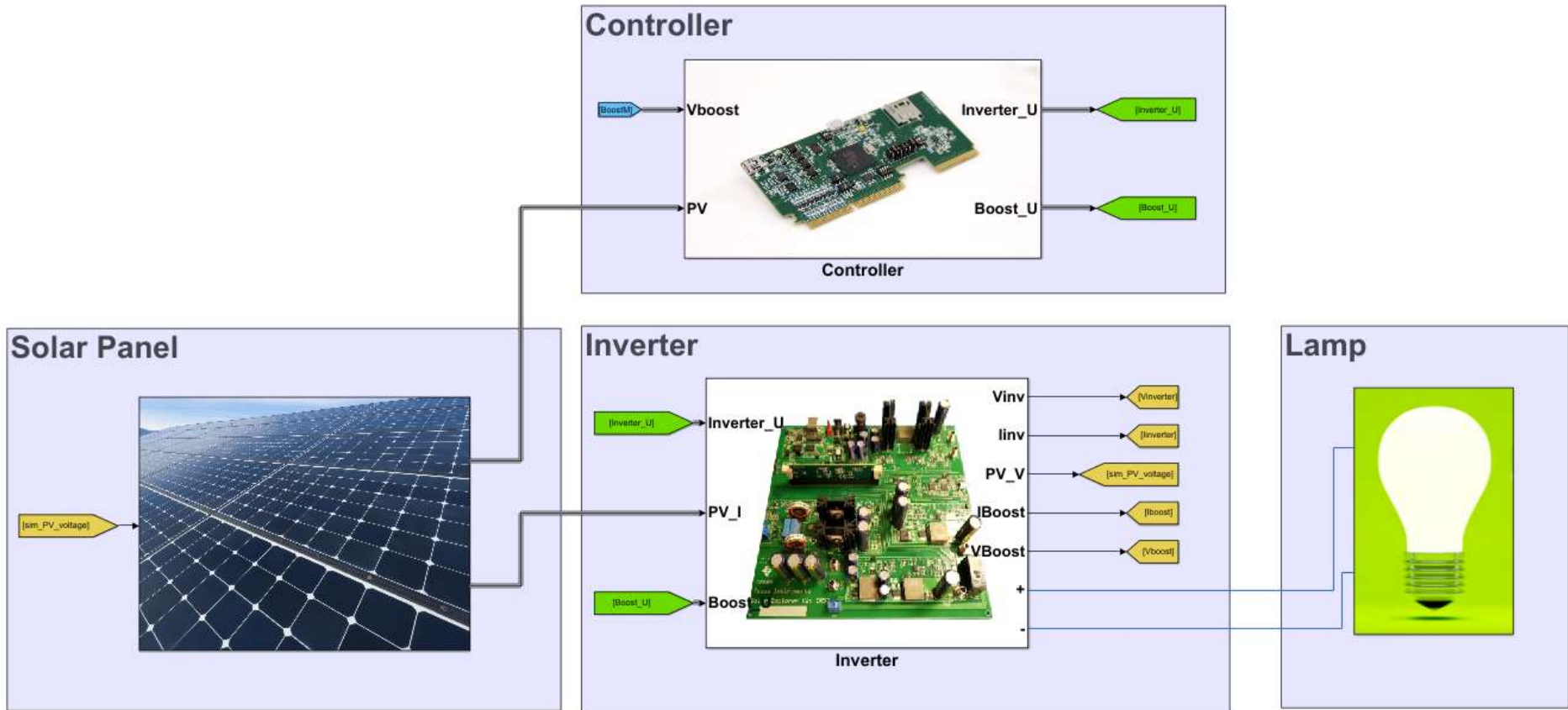


# Solar Inverter for Real-time Testing

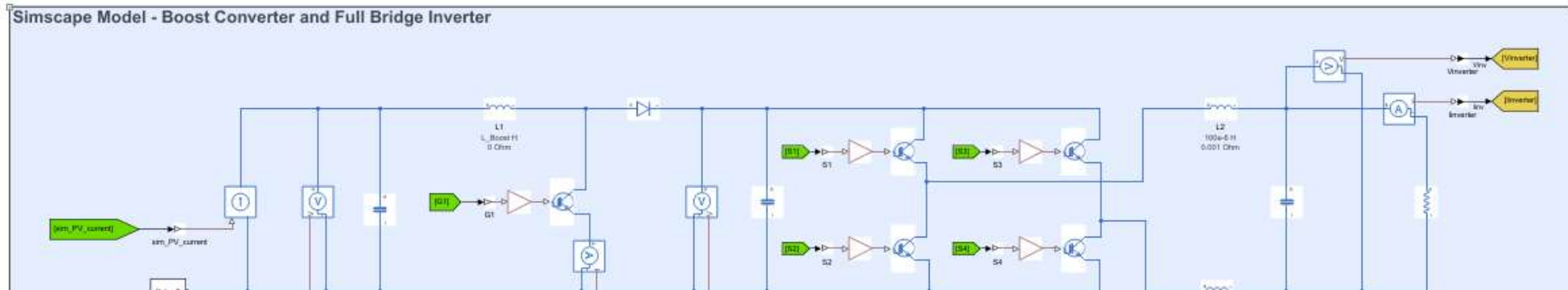




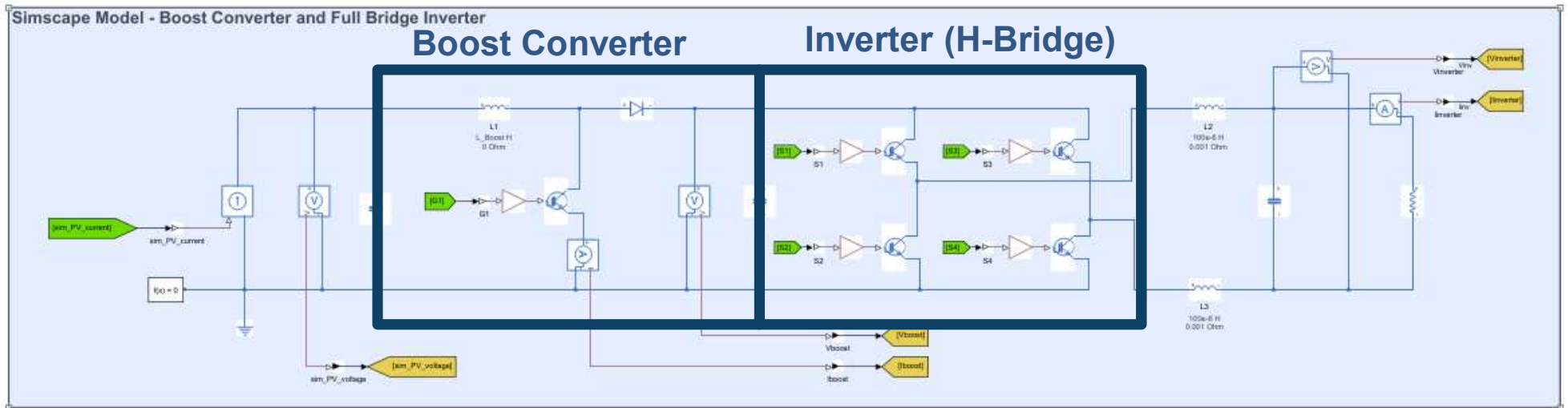
# Step 1: Create a Model (Desktop Simulation)



# Inverter and Boost Converter Model



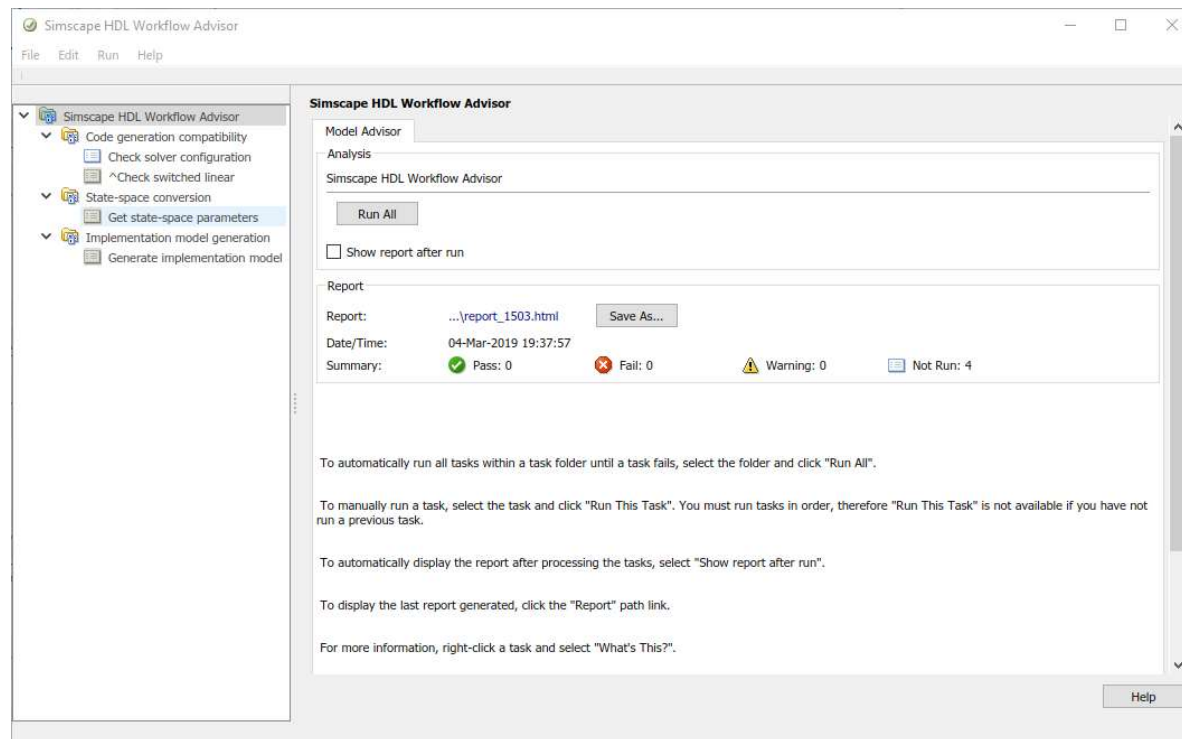
# Inverter and Boost Converter Model



**Need to convert continuous models to discrete models appropriate for an FPGA**

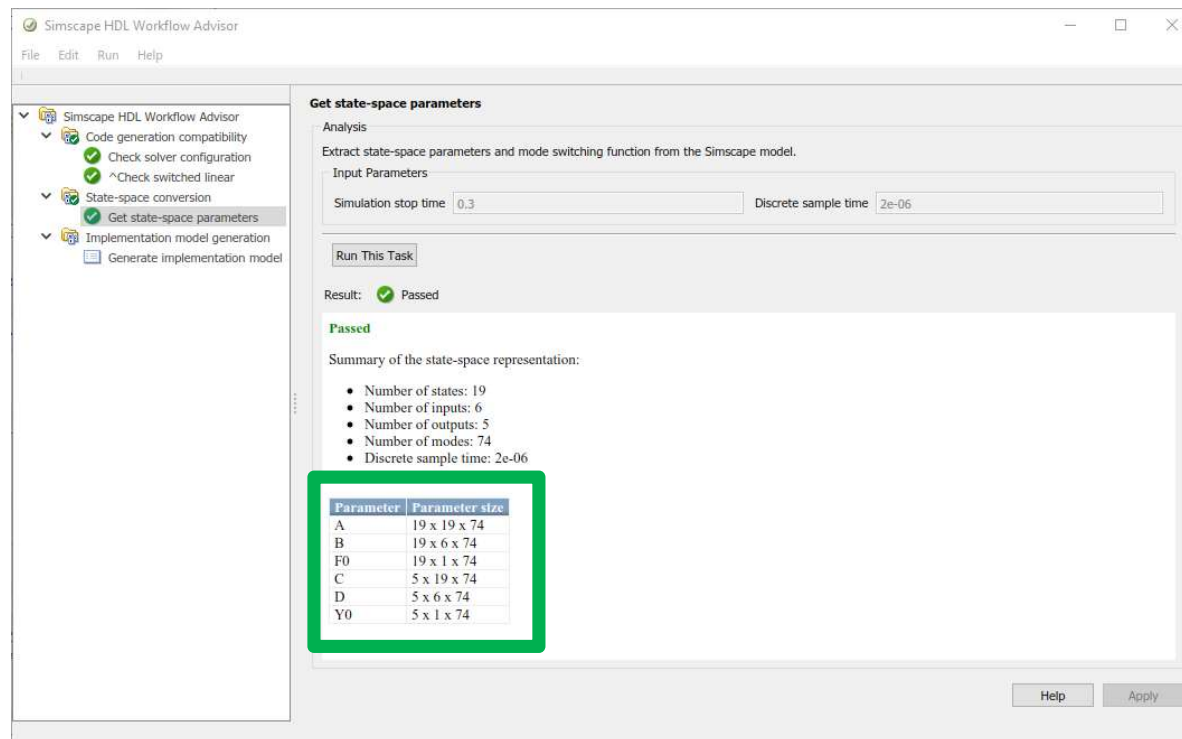
# Convert to HDL: Simscape HDL Workflow Advisor New Feature 2018b

- Run 'sschdladvisor' on model



# Extract State Space Parameters (Linearize the System)

- Simulation must contain all relevant switching states



**Get state-space parameters**

Analysis

Extract state-space parameters and mode switching function from the Simscape model.

Input Parameters

Simulation stop time: 0.3      Discrete sample time: 2e-06

Run This Task

Result: ✔ Passed

**Passed**

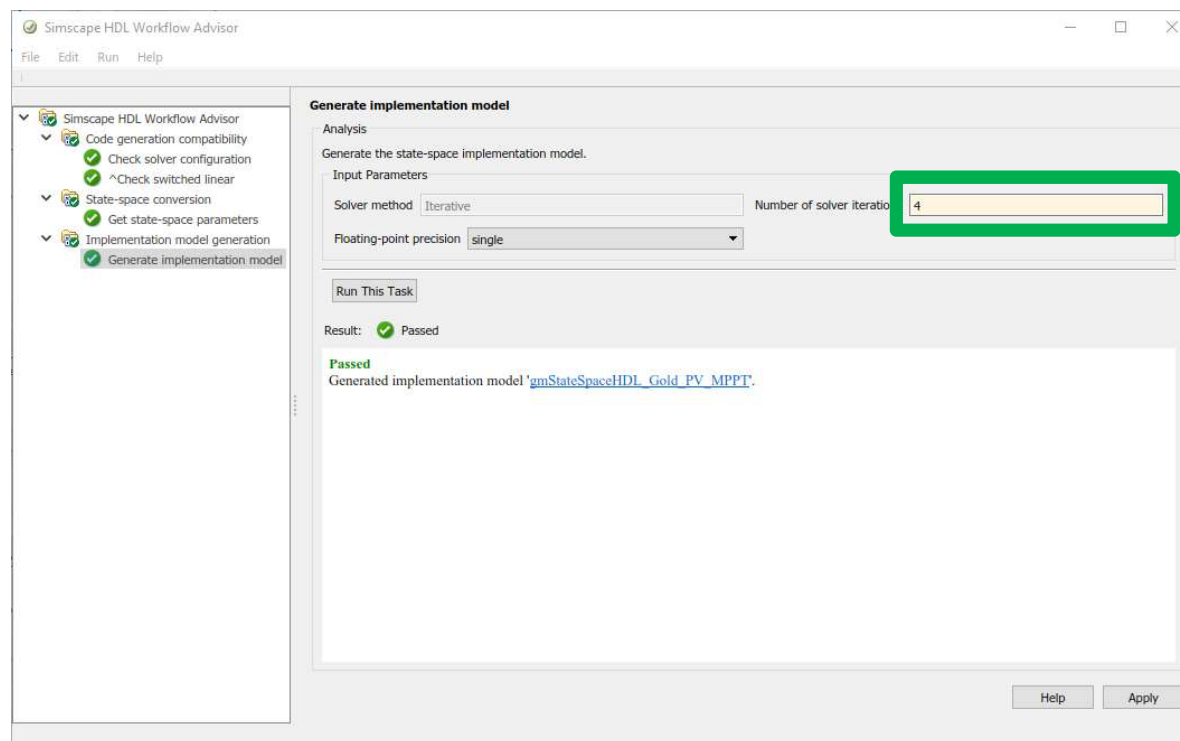
Summary of the state-space representation:

- Number of states: 19
- Number of inputs: 6
- Number of outputs: 5
- Number of modes: 74
- Discrete sample time: 2e-06

Parameter	Parameter size
A	19 x 19 x 74
B	19 x 6 x 74
F0	19 x 1 x 74
C	5 x 19 x 74
D	5 x 6 x 74
Y0	5 x 1 x 74

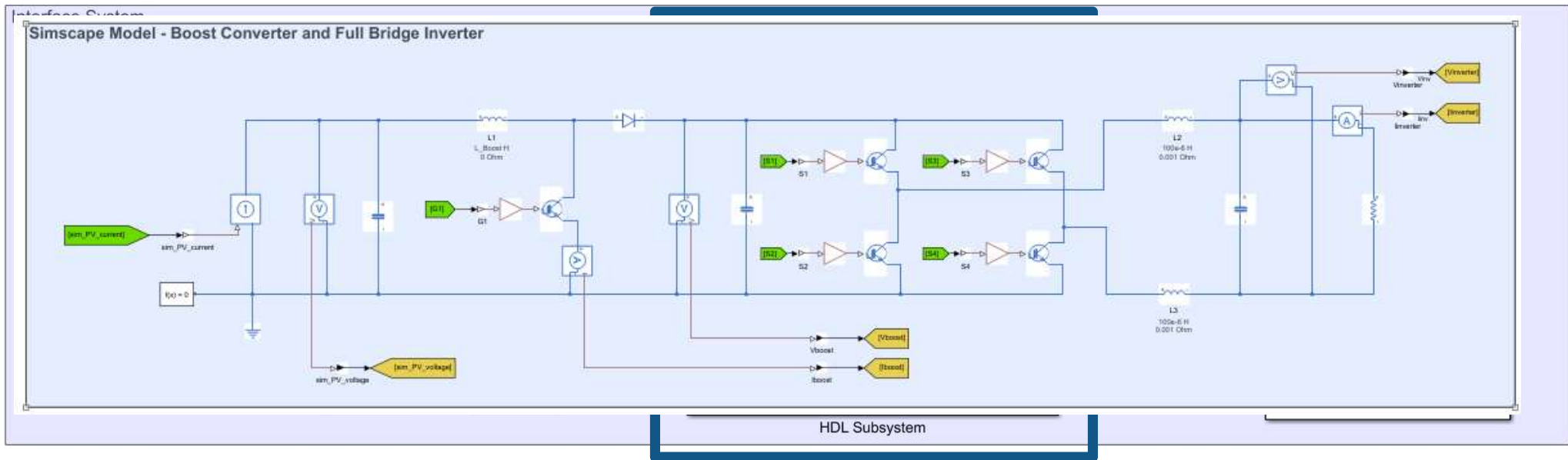
# Simscape HDL Workflow Advisor

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



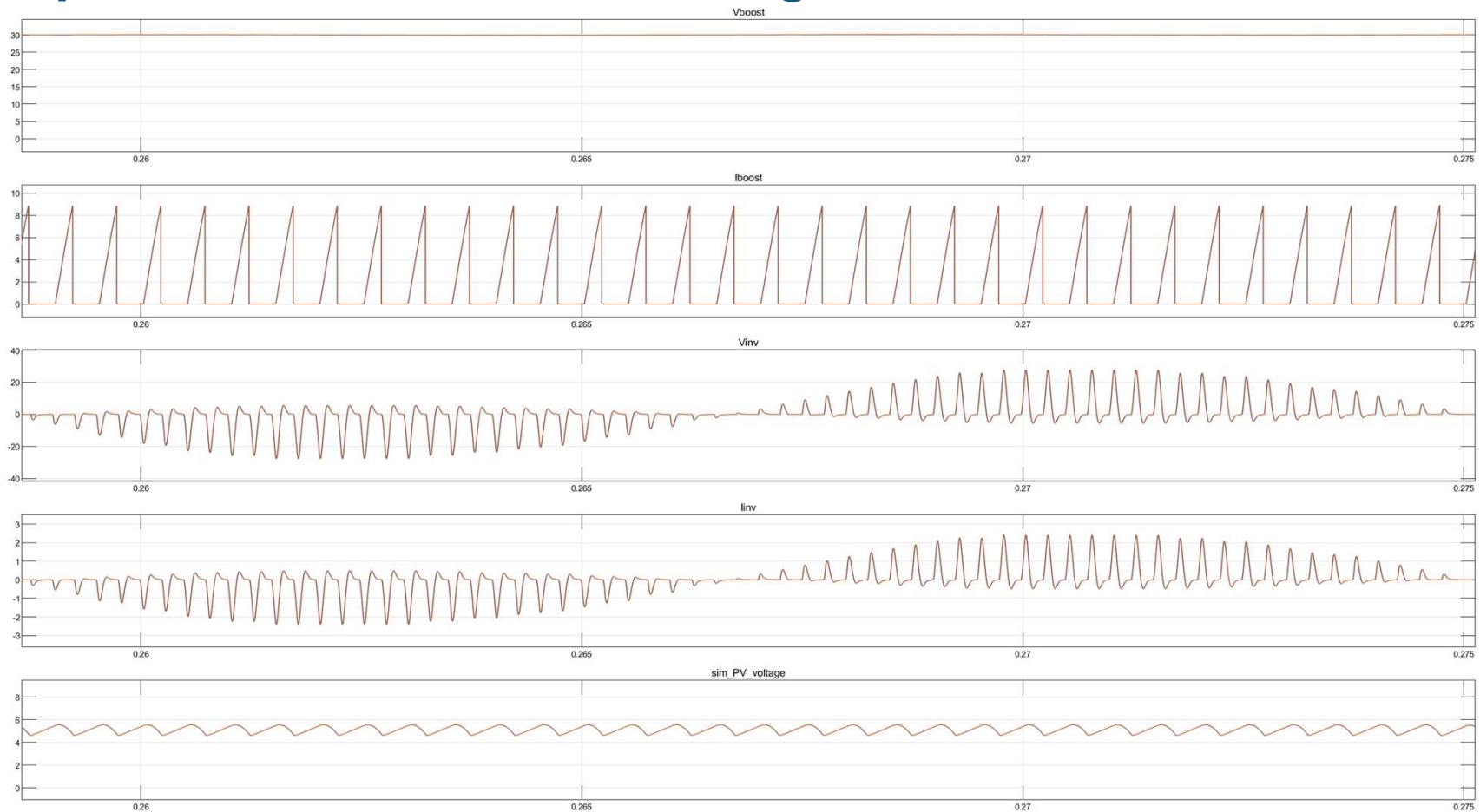
# Implementation Model

Replaces Simscape with State-space

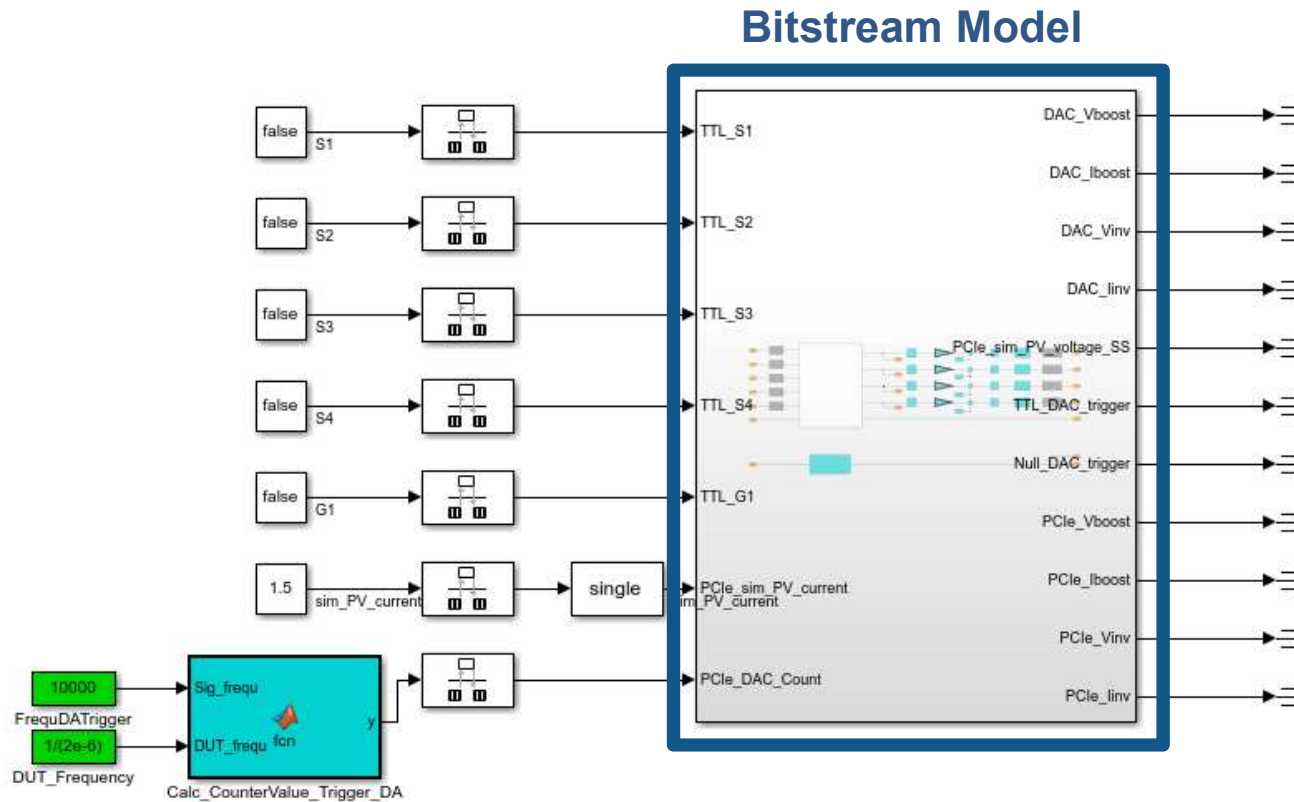




# Compare Generated Model to Original

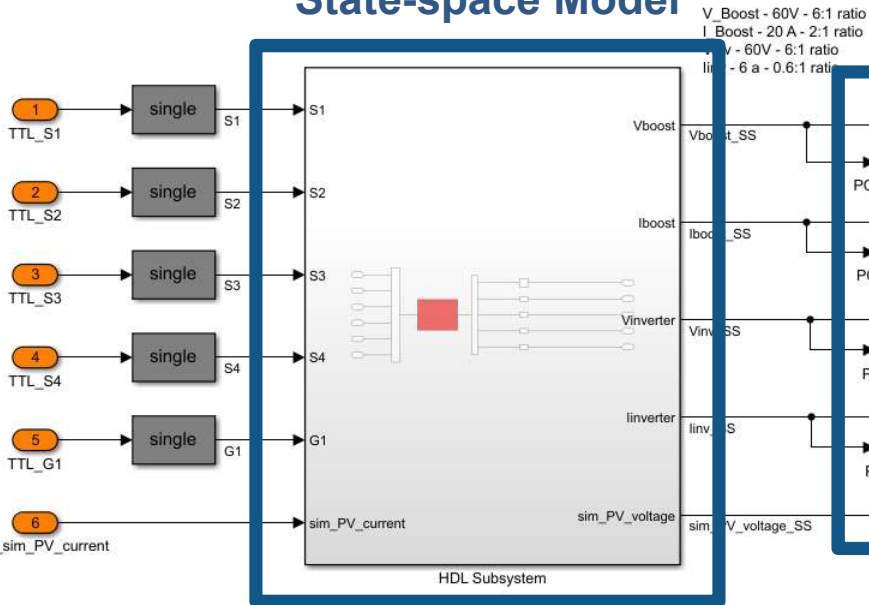


# Create Custom Bitstream for Real-time FPGA

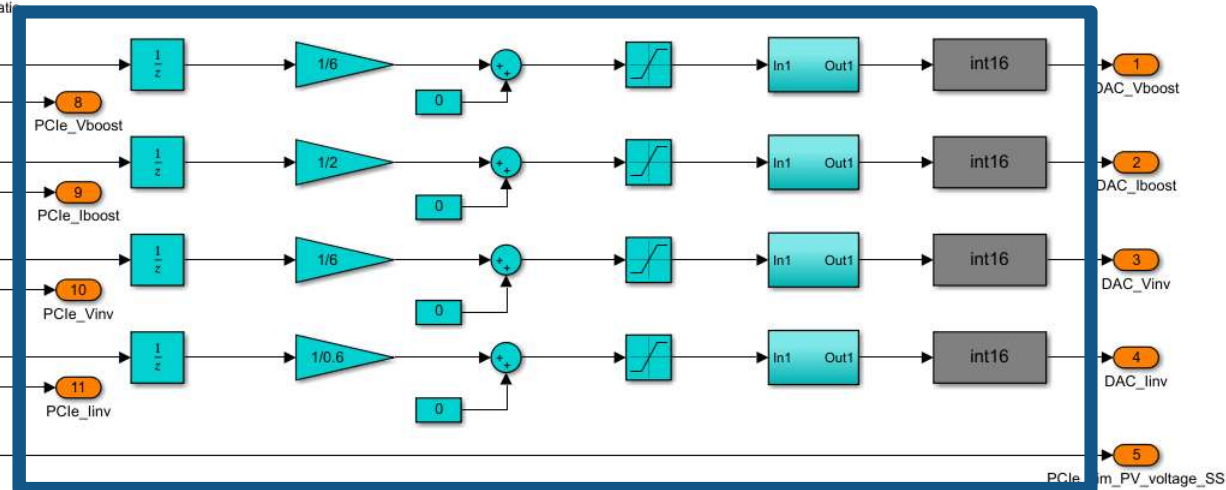


# Create Custom Bitstream for Real-time FPGA

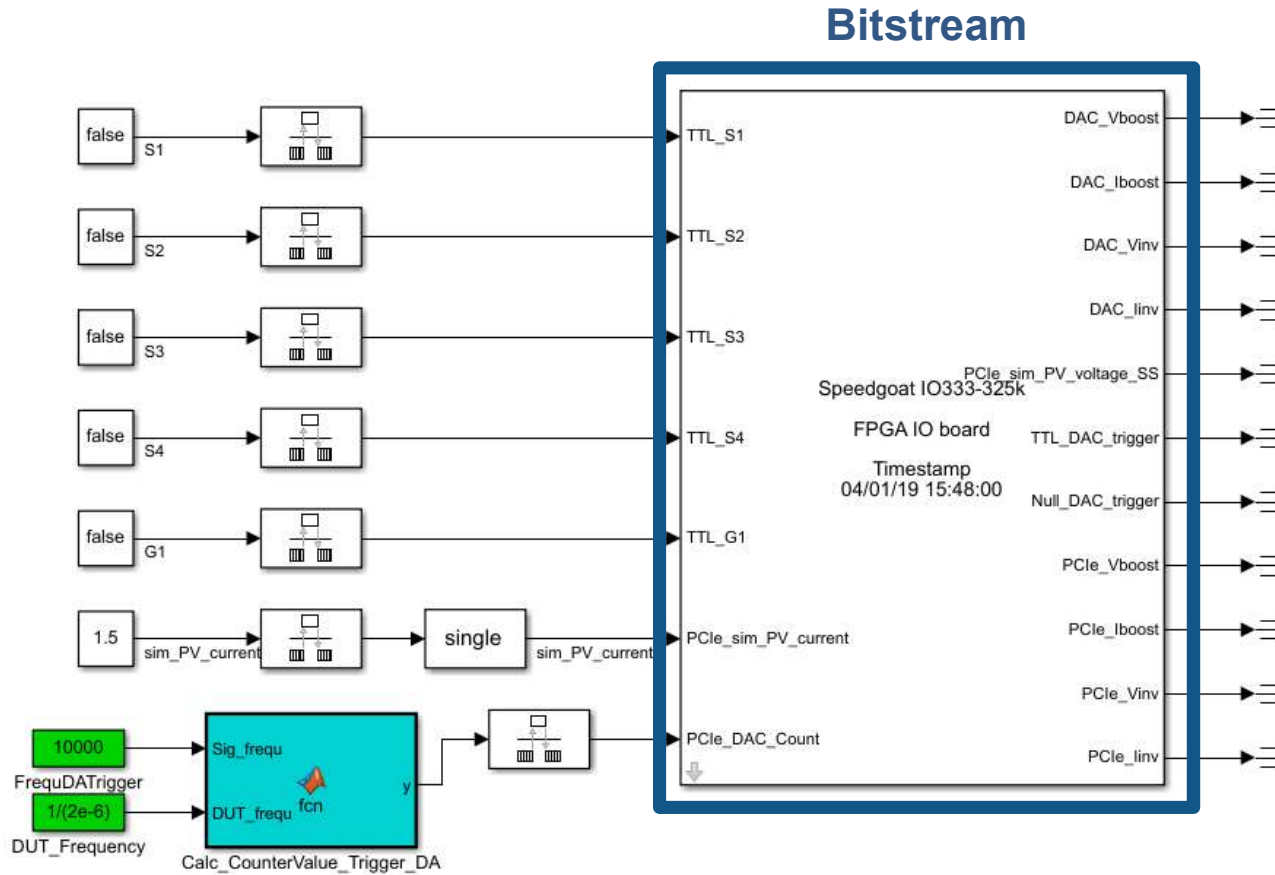
## State-space Model



## Analog Peripheral Scaling



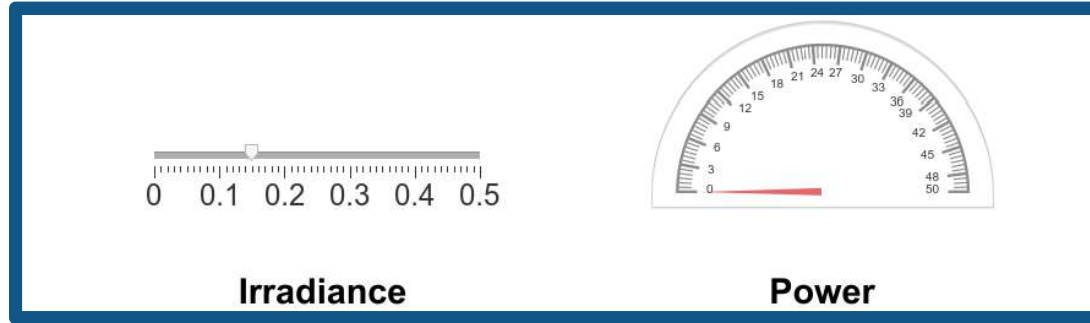
# Create Custom Bitstream for Real-time FPGA



Generated by HDL Workflow Advisor on 04-Jan-2019 15:56:21

# Combine with Simulink Model

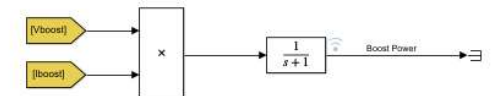
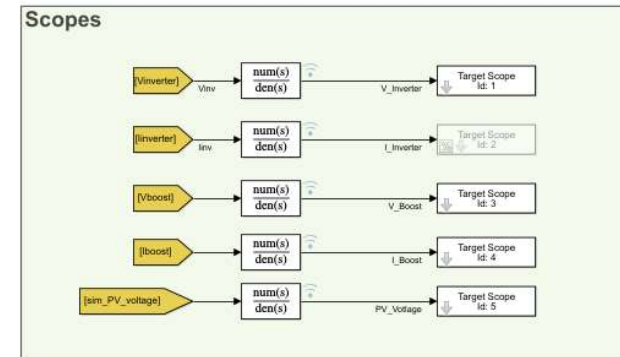
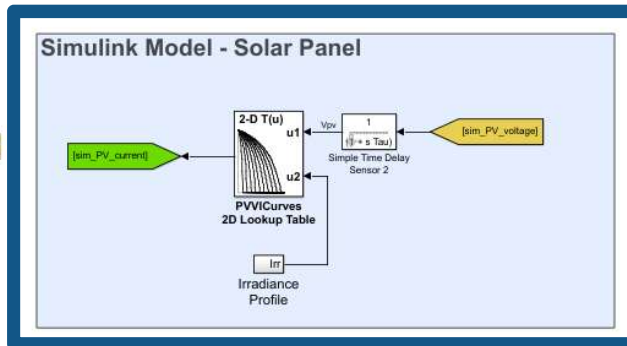
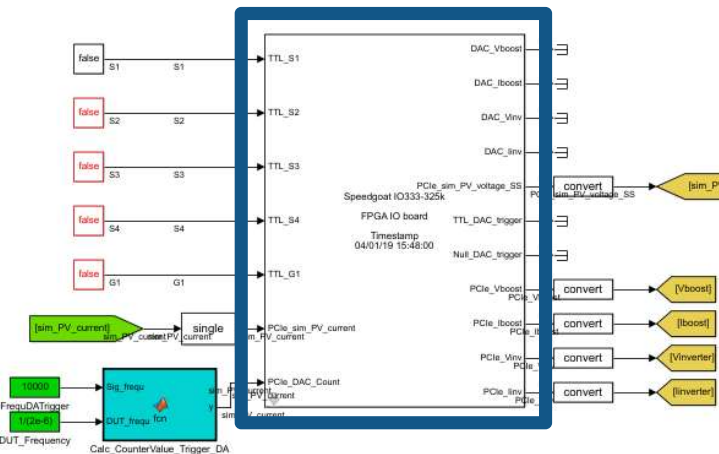
## Dashboard Real-time Interface



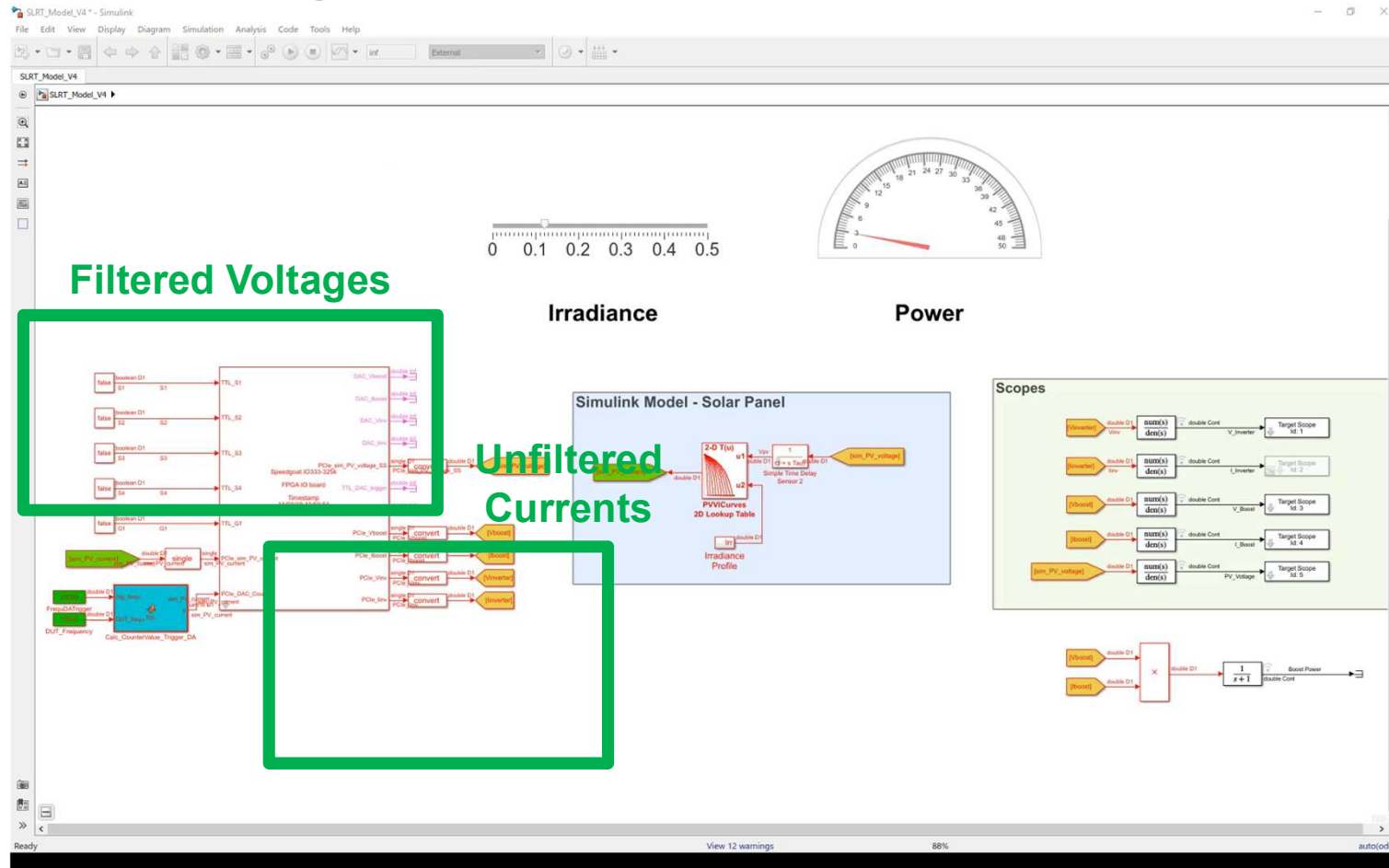
## Bitstream

## CPU Based Model

## Scopes



# 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 Kintex 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!