Power Electronic Systems
Power Electronics Applications

Electric vehicles and charging stations

Renewable energy

Rail

Lighting
Our Project Today

DC/DC LED Developer's Kit

LED Head Lamp
Mercedes headlamp technology – video
(Ref: Mercedes Benz Website)
Why Simulink for Power Electronics Control?

- Extensive library of sources and loads
  - PV arrays, batteries, motors
- Broad range of power electronics models
  - Average value, fast ideal switching, physics-based
- Advanced control design capabilities
  - Auto-tuning in time & frequency domains for single and multiple loops
- Generation of readable, compact and fast code from models
  - C for microprocessors, HDL for FPGAs

Customers routinely report 50% faster time to market
ABB Accelerates the Delivery of Large-Scale, Grid-Connected Inverter Products with Model-Based Design

Challenge
Accelerate the design and delivery of large, grid-connected power inverter products

Solution
Use Model-Based Design to model, simulate, and generate control software for modular, scalable power electronic building blocks

Results
- Prototypes delivered in two weeks, not three months
- Defect-free, optimized code generated
- Potential damage to test equipment mitigated

“Simulink and Embedded Coder enabled us to open the door to new markets. With increased productivity from extensive simulation and efficient code generation, we have confidence in our ability to produce the systems that larger customers are asking for in the time frames they want.”
- Dr. Robert Turner, ABB

Link to user story
Challenges for Power Electronics Engineer

- Examine effect of source and load on power converter operation
- Test embedded software for complete range of operation and fault conditions
- Design and implement digital controls in SPICE simulator tools only
- Identify errors during software-hardware integration testing
- Qualify designs to meet regulatory and industry standards
Power Converter Control Design Workflow Tasks

- Size inductor, capacitor and understand the behaviour in continuous and discontinuous mode
- Determine power losses and the thermal behaviour of the converter
- Design control algorithm based on time/frequency domain specification
- Implement power electronic controls on an embedded platform
Let’s get to it!
Power Converter Control Design Workflow Tasks

- Size inductor, capacitor and understand the behaviour in continuous and discontinuous mode
  - Determine power losses and the thermal behaviour of the converter
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  - Implement power electronic controls on an embedded platform
Recap: Size Inductor, Capacitor and Understand the Behaviour in Continuous and Discontinuous mode.

What we did:
• Use simulation to design DC to DC converters
• Optimize component sizing using simulation driven analysis
Power Converter Control Design Workflow Tasks

- Size inductor, capacitor and understand the behaviour in continuous and discontinuous mode

- **Determine power losses and the thermal behaviour of the converter**

- Design control algorithm based on time/frequency domain specification

- Implement power electronic controls on an embedded platform
Recap: Determine Power Losses and Simulate Thermal Behaviour of the Converter.

What we did

- Use semiconductor blocks from Simscape Electrical to model the non-linear switching behavior of SEPIC converter
- Leverage the multi-domain simulation capability of Simscape in understanding the thermal dynamics
New: Convert SPICE models into Simscape components

- Incorporate manufacturer specific behavior into simulation
- Easily parameterize the model
- Combine existing electronic models with other domains (such as thermal), control algorithms, signal processing, all in a single environment
Power Converter Control Design Workflow Tasks

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Recap: Design Control Algorithm Based on Time/Frequency Domain Specifications

What we did
• Identify plant model from input output simulation data
• Use auto tuning algorithms to tune the control gains
Power Converter Control Design Workflow Tasks

- Size inductor, capacitor and understand the behaviour in continuous and discontinuous mode
- Determine power losses and the thermal behaviour of the converter
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What do we want to do:

- Verify the controller for various test cases on real HW
- Generate code from MATLAB and Simulink models optimized for embedded platforms (DSP and FPGA)
- System-level test using Hardware-in-the-Loop
Challenges of a Software Engineer

- Collaborate in multidisciplinary teams
- Create working code
- Achieve required efficiency
- Respect project timeline
Integrated Development Environment
Rich Environment Editor: Simulink Editor, Rich Annotations

Add images, tables, and bulleted lists to your model

- Rich text with:
  - Bold, italic, font name, font size, highlight etc.
  - Bulleted and enumerated lists
  - Tables
  - Hyperlinks (proper URLs)
  - Images

- Image annotations with callbacks
- Author your content directly in the editor or paste clipboard content copied for Word, Excel, HTML, etc.
Integrated Development Environment

Simulink Projects Becomes MATLAB and Simulink Projects
Integrated Development Environment

Manage projects

Integrate with Source Control

Standardize team environment

Execute dependency analysis

Support for change management

Build & share best-practices

Automate tasks

+ Your Company Library v1.3
+ Your Project Libraries
Integrated Development Environment
Dependency Analysis

- Visualize file dependencies, associations, and missing files
- Visualize the impact of changes to the files within your project
- Understand the impact of requirements changes on your design
- Store and access previous dependency analysis results
Integrated Development Environment

Graphical Model Comparison

- Graphical and Binary files comparison
- View functional and non-functional changes
- Two and Three Way Merge Capability
Replace Hand Coding with Code Generation

```
function [symbols, weights] = gainctrl(rxsig, train)
% 1-tap adaptive equalizer using LMS or RLS algorithm

% Equalizer settings
lambda = 0.99;
Delta = 0.1+i0; % C Code
weights = 0+i0;

for n = 1:length(rxsig)
    u = rxsig(n); % C Code
    y = conj(weights) * u;
    if n==length(train)
        d = train(n);
    else
        d = detect(real(y)) + 1j*detect(imag(y));
    end % C++ Code
    % Single-tap RLS
    Delta = 1/(lambda/Delta + u*conj u);
    G = Delta * u;
    e = d - y; % Symbol estimation
    weights = weights + G*conj(e);
    symbols(n) = y;
end
```

MATLAB
Hardware support

Browse Support for:

- Lab Instruments
  Examples: Visa Support from Instrument Control Toolbox

- Data Acquisition Systems
  Examples: NI-DAQmx Support from Data Acquisition Toolbox

- Image and Video Acquisition and Camera Applications
  Examples: Web Cam I/O with MATLAB and Simulink, Microsoft Kinect Support from MATLAB and Simulink

- Streaming Audio with MATLAB and Simulink

- FPGA-in-the-Loop Platforms

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Browse Support for:

- Programming Microprocessors with C/C++
  Examples: Low Cost Simulink Targets, ARM Cortex Targets, Embedded Coder Hardware Support Packages

- Programming FPGAs
  Examples: Programming SDR Algorithms with HDL, Motor Control with Zynq

- Programming PLCs

- Real-Time Simulation, Testing, and Hardware-in-the-Loop
  Examples: Simulink Real-Time Solutions with Speedgoat

- Audio Related Targeting
Automatically Generate C/C++ Code

Full bi-directional traceability!!
Measure On-Target Code Performance

Instrument generated code for On-Target Execution Profiling
Optimize for C2000 to Improve Execution Performance

Code replacements for library 'TI C28x'. The library comprises:
- TI C28x
  - IQmath_tfl_table.mat
  - TI_C28x_addsub_tfl_table.mat
- TI C28x with C99 extensions
  - TI_C28x_iso_tfl_table.mat
  - TI_C28x_tfl_table.mat

To see the replacements and misses in the Code Replacement Viewer, look here.

1. Multiplication operator replacements [hide]

The following table provides a mapping from the multiplication operators used from the selected Code Replacement Library to the blocks in the model that triggered the replacement.

<table>
<thead>
<tr>
<th>Function</th>
<th>Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>_IQ22mpy132</td>
<td>&lt;S&gt;/Gain2</td>
</tr>
<tr>
<td>_IQ22mpy132</td>
<td>&lt;S&gt;/Gain3</td>
</tr>
<tr>
<td>_IQ22mpy132</td>
<td>&lt;S&gt;/Gain4</td>
</tr>
<tr>
<td>_IQmpy</td>
<td>&lt;S&gt;/Gain</td>
</tr>
<tr>
<td>_IQmpy</td>
<td>&lt;S&gt;/Gain</td>
</tr>
<tr>
<td>_IQmpy</td>
<td>&lt;S&gt;/Gain1</td>
</tr>
<tr>
<td>_IQmpy</td>
<td>&lt;S&gt;/Gain5</td>
</tr>
</tbody>
</table>
Automatically Generate VHDL/Verilog Code

Mix Fixed-Point and Native Floating Point

Full bi-directional traceability!!

Requirements
Automated Fixed-Point Optimization and Analysis

Conversion goals:

- 1% relative tolerance -- Vout1
- Stable controller behavior
- Manage fixed-point bit growth
- Automated workflow
Automated Fixed-Point Optimization and Analysis

- Simulate dynamic behavior of fixed-point model
- Analyze fixed-point quantization impact to defined tolerances
- Analyze bit-growth after fixed-point conversion
Why do we need Hardware-in-the-Loop (HIL) Testing

- Can replace prototypes or production hardware with a real-time system
- Safer than most power electronics hardware
- Easier to automate testing and test fault conditions
- Start many design/test tasks earlier
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Virtual Simulation (Plant)
Strategies Hardware-in-the-Loop (HIL) Testing

- **Deploy Simscape models on CPUs**
  - Using Average-value models to validate controller behaviour
  - To validate electronic switching converters
    - $\leq 2$kHz switching frequency
    - Where step-sizes $\geq 10$us are sufficient

- **Deploy Simscape models on FPGAs**
  - To validate electronic switching converters
    - $> 2$kHz switching frequency
    - Where step-sizes $< 10$us are required
Using Average-value Model for HIL

- A simplified model with acceptable tradeoff between fidelity and performance

- Average models could be obtained using
  - Simscape
  - Small signal analysis
  - Frequency response estimation
  - System identification
Using Simscape (FPGA) for HIL

Simscape model

Simulink state-space model

FPGA

Simscape HDL Advisor

HDL Workflow Advisor
High sample rates (small time steps) are required to capture fast transients in systems like power electronics.

**Resolution:** milliseconds

**Resolution:** microseconds

**Resolution:** seconds

**Why is FPGA-based HIL Relevant to Power Electronics?**

**The Need for Small Time Step Simulations**

**MATLAB EXPO 2019**
Recap: Implement Power Electronics Control on an Embedded Platform

What we did:
• Verify the controller for various test cases on real HW
• Generate code from MATLAB and Simulink models optimized for embedded platforms (DSP and FPGA)
• System-level test using Hardware-in-the-Loop
Power Converter Control Design Workflow Tasks

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Alstom Generates Production Code for Safety-Critical Power Converter Control Systems

Challenge
Design and implement real-time power conversion and control systems for trams, metros, and railways

Solution
Use MathWorks tools for Model-Based Design to design, simulate, and automatically generate production code for safety-critical transportation systems

Results
- Development time cut by 50%
- Defect-free, safety-critical code generated and certified
- Common language established

"MathWorks tools enable us to control every line of code, and the generated code is readable, fast, and compact. Also, MathWorks tools are industry-standard, with extensive packages and broad support for embedded targets."

- Han Geerligs, senior engineer, Alstom
Summary

▪ Simulation to validate assumptions early

▪ Common language to enable collaboration

▪ Verification from start to end:
  Virtual Prototypes ➔ Physical Prototypes ➔ Hardware-in-the-Loop

▪ Code generation for rapid design iterations
Related Trainings

- **Simscape**
  - Modeling Physical Systems with Simscape
  - Modeling Electrical Power Systems with Simscape

- **Embedded Code Generation**
  - Embedded Coder for Production Code Generation

- **HDL Code Generation**
  - Generating HDL Code from Simulink

https://ch.mathworks.com/services/training.html