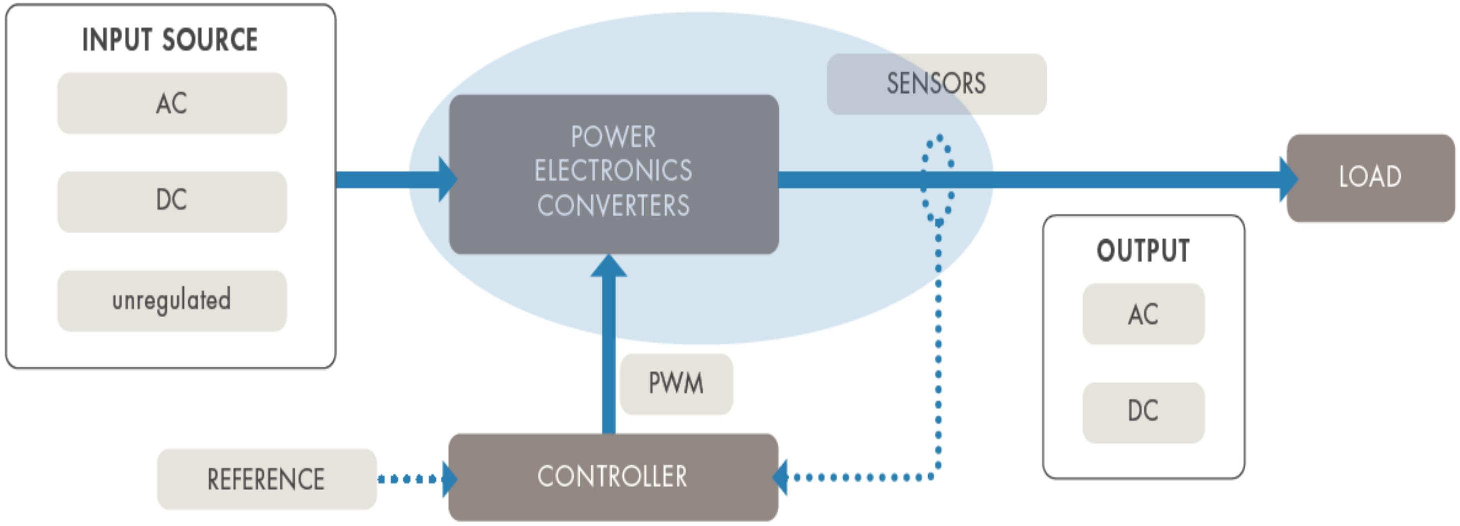
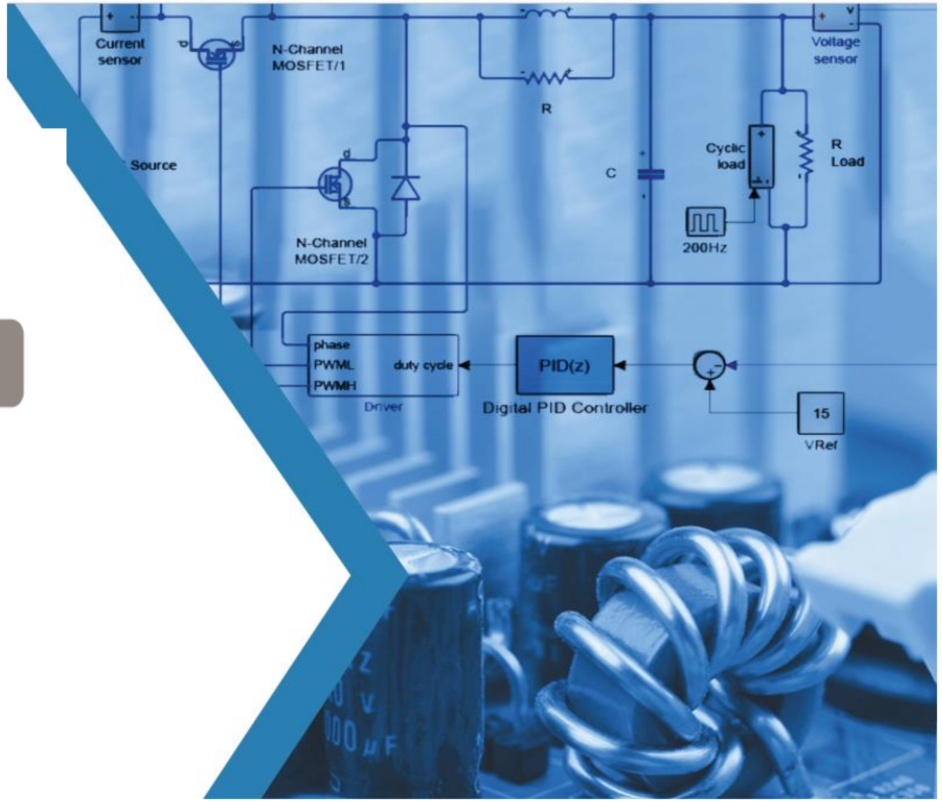
MATLAB EXPO 2019

Sviluppare controlli digitali per convertitori elettronici di potenza

Aldo Caraceto

Power Electronic Systems





Power Electronics Applications


Electric vehicles and charging stations

Rail

Renewable energy

Lighting

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 processor

Challenges for Power Electronics Engineer

- Understanding the impact of the power source and load on the operation of the power converter
- Testing embedded software for a complete range of operating and fault conditions

- Designing and implementing digital controls using *only* SPICE simulator tools

- Catching errors late in a program during software-hardware integration testing
- Qualifying designs to meeting regulatory and industry standards for efficiency, power quality, and safety

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

Our Project Today

DC/DC LED Developer's Kit

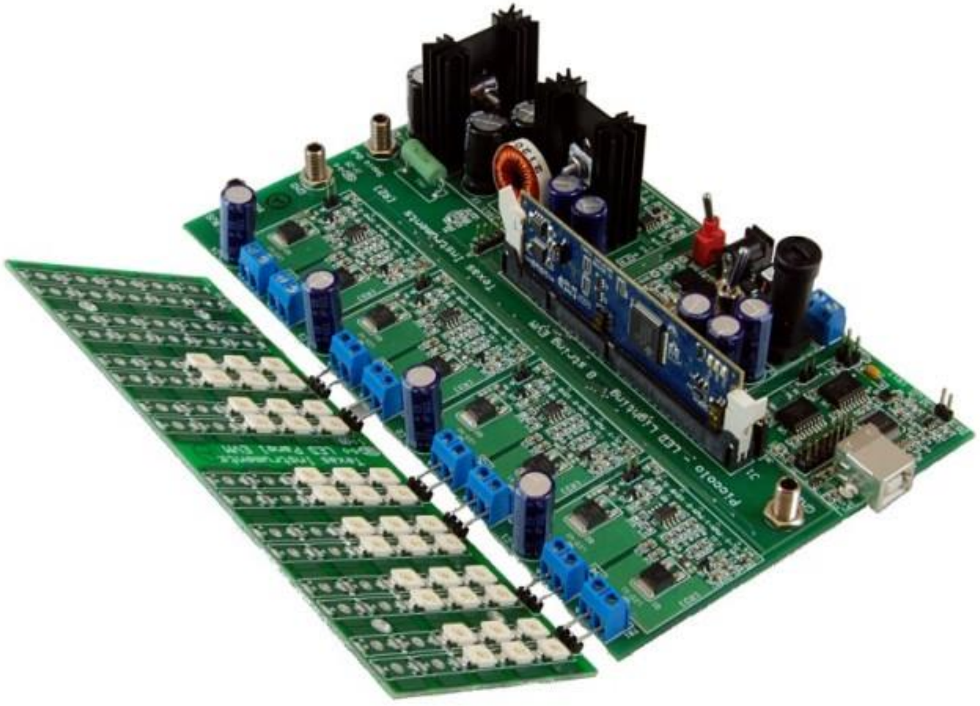


Fig 1: TMDSDCDCLEDKIT

LED Head Lamp

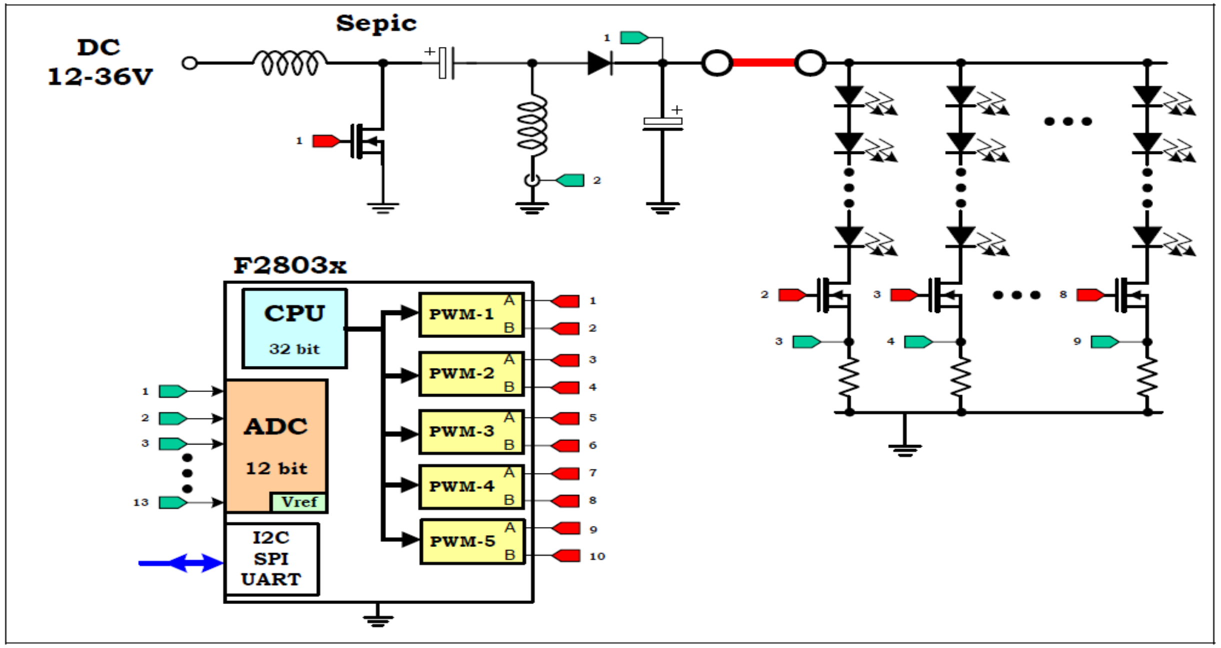


Fig4: DC/DC LED Lighting Board Block diagram with F28035

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Let’s get to it!

Power Converter Control Design Workflow Tasks

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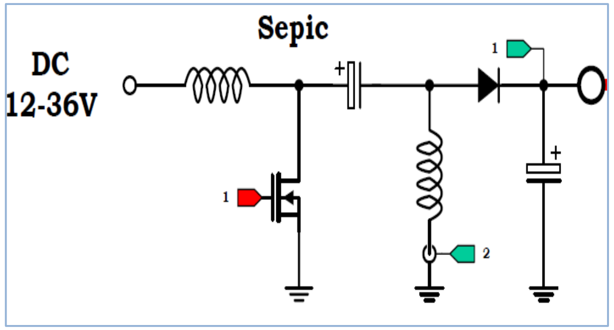
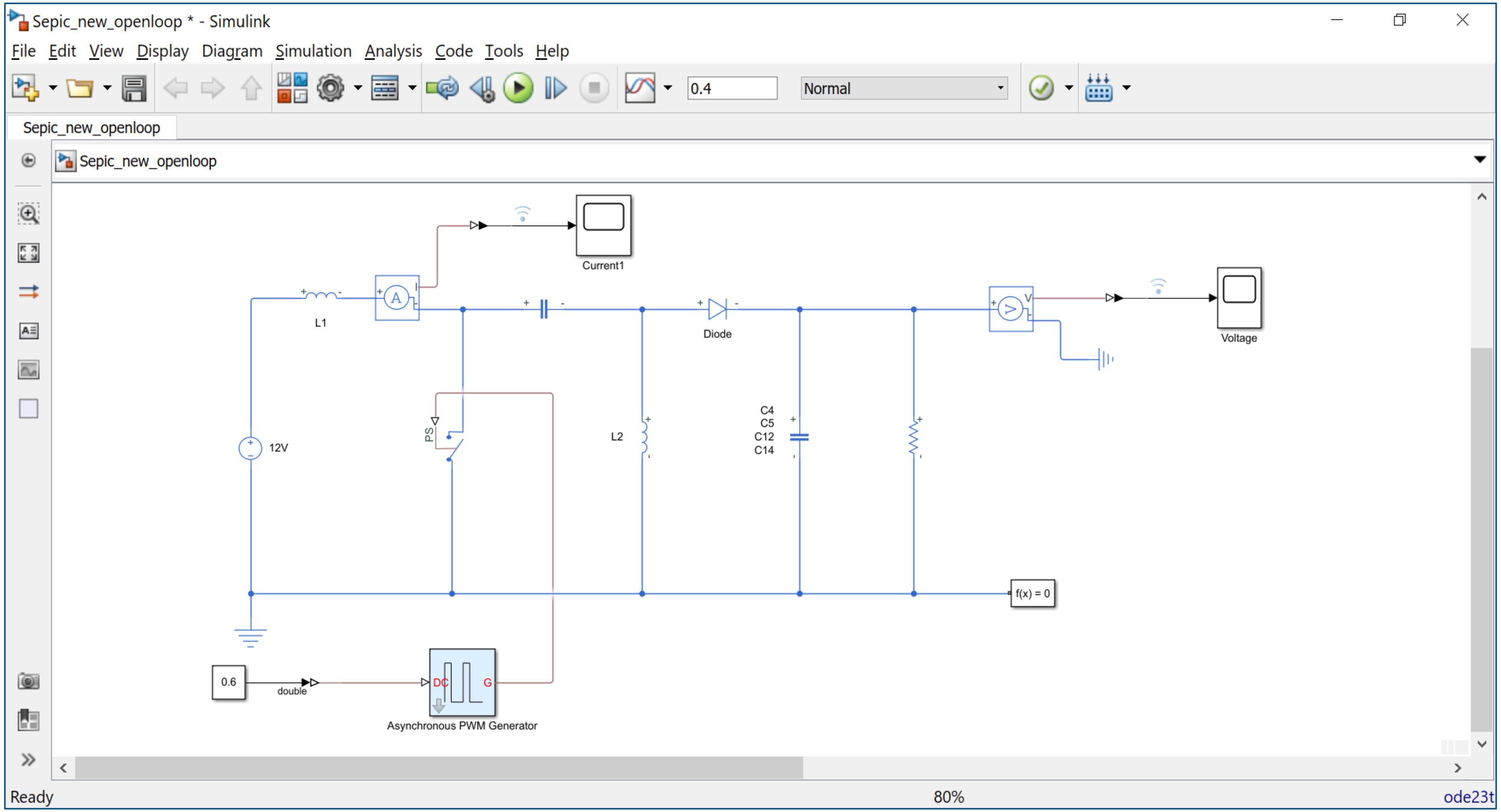
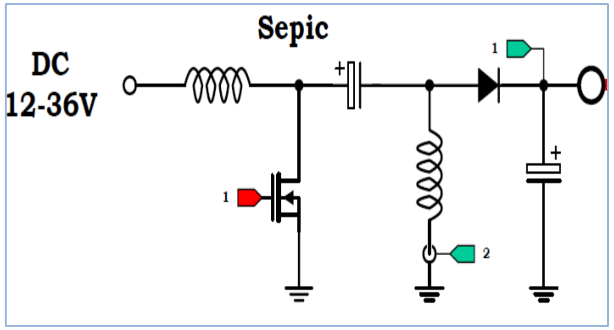
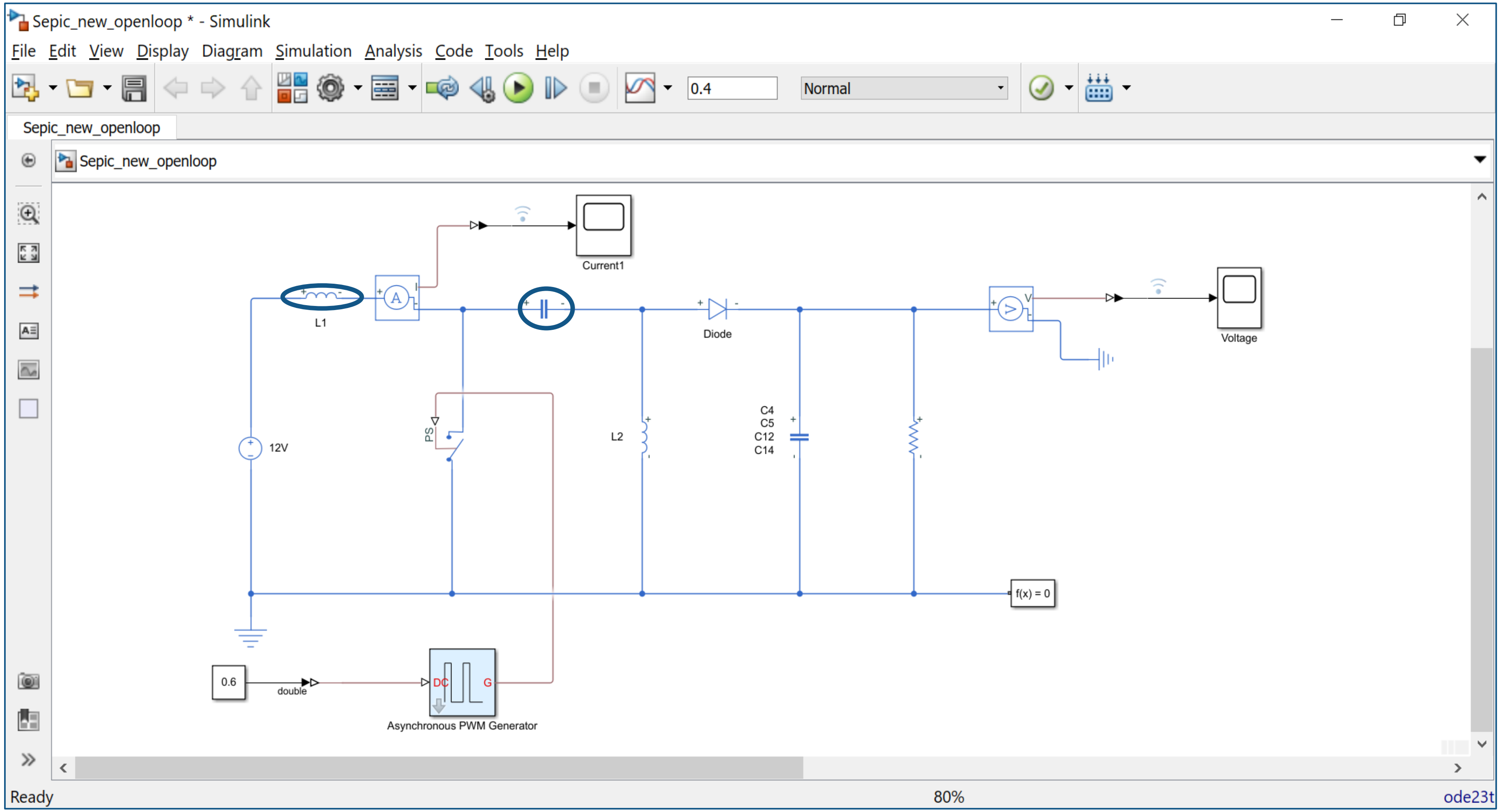
Simscape model for DC-DC Sepic Converter



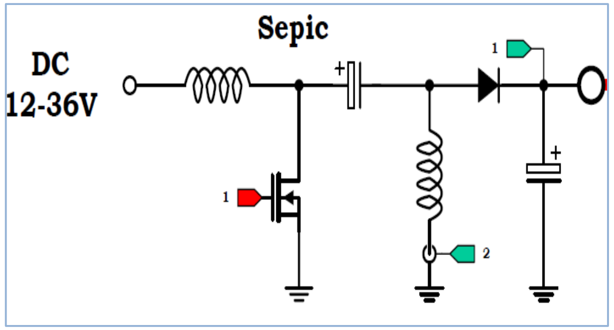


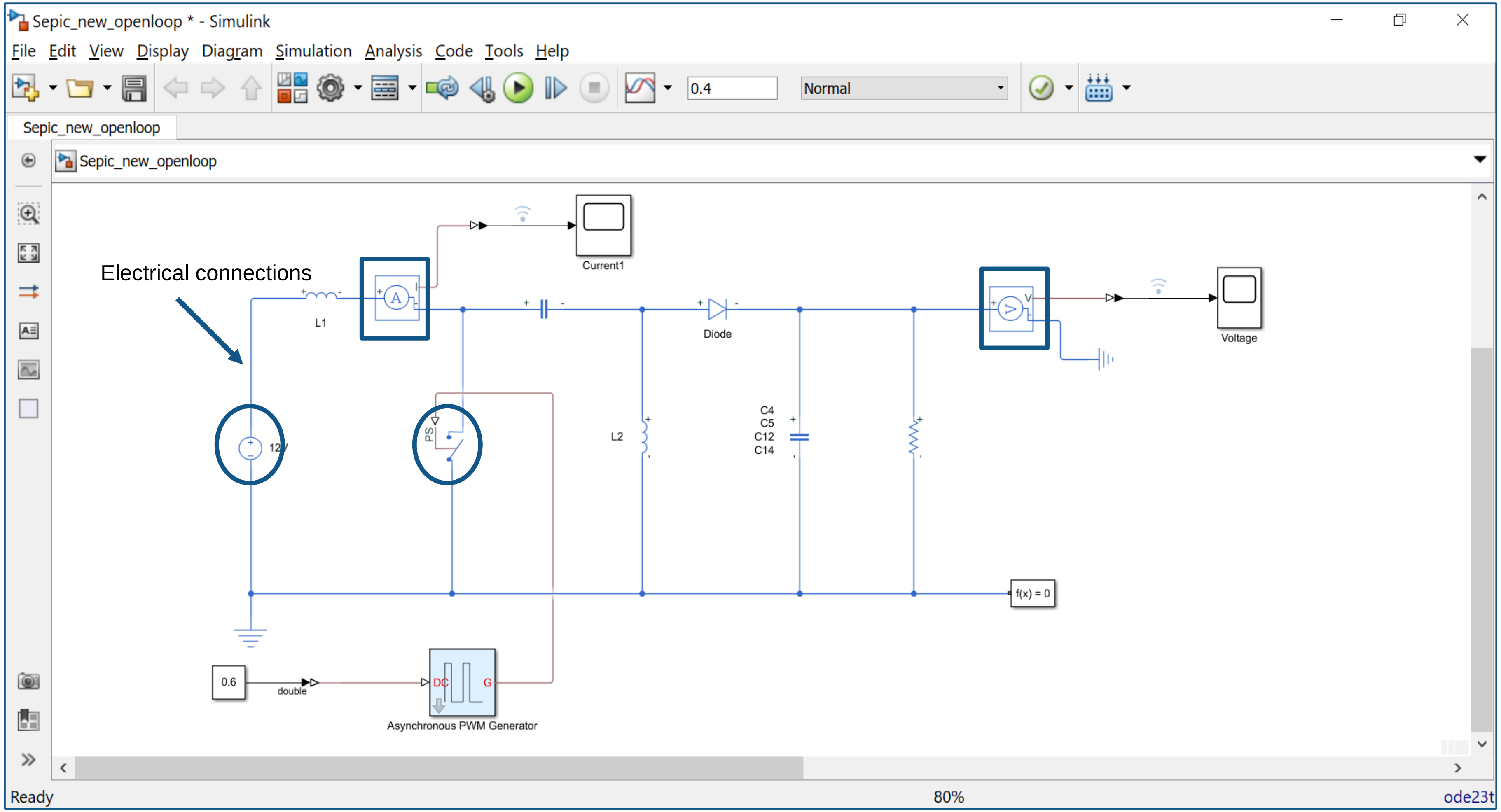
Simscape model for DC-DC Sepic Converter

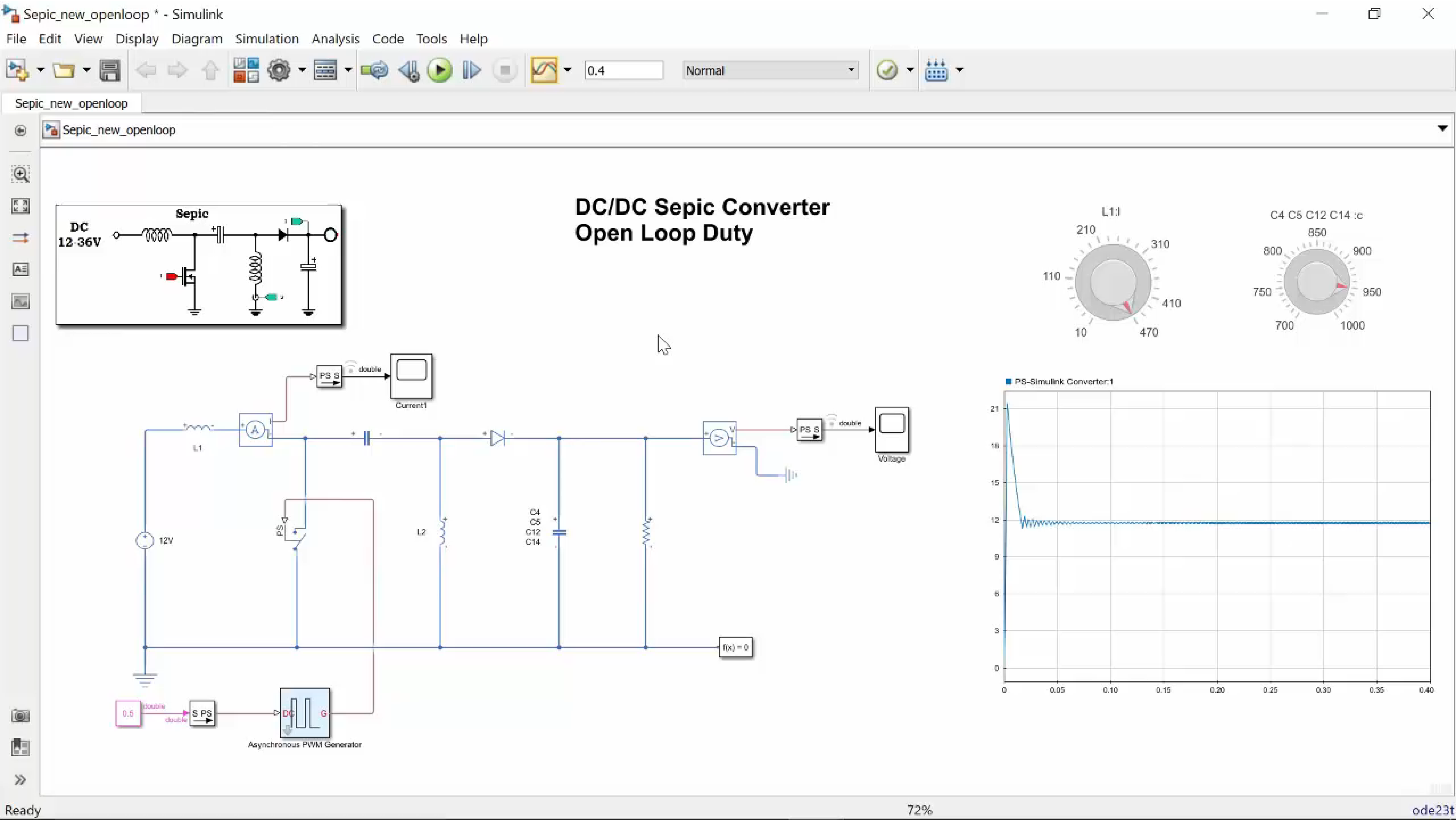




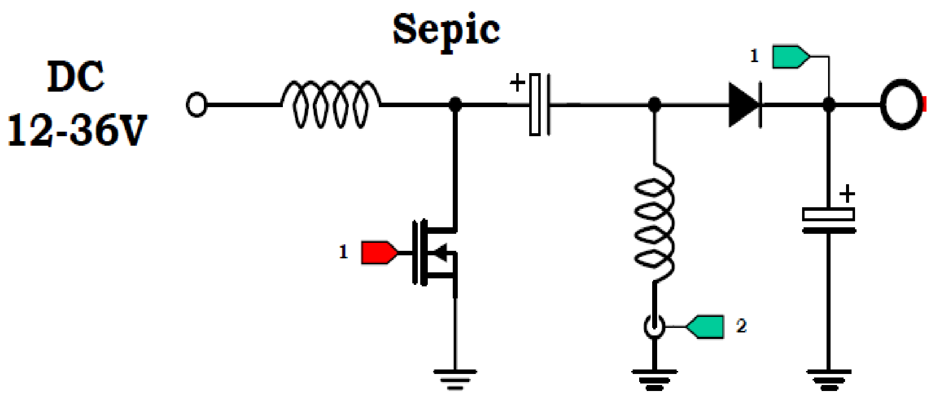
Simscape model for DC-DC Sepic Converter

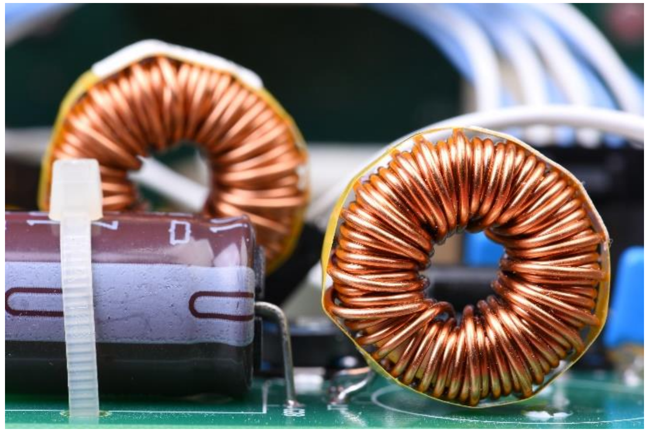





Sepic_new_openloop * - Simulink
File Edit View Display Diagram Simulation Analysis Code Tools Help
0.4
Normal
Sepic_new_openloop
Sepic_new_openloop
DC/DC Sepic Converter
Open Loop Duty
Sepic
DC
12-36V
L1:l
210
310
110
410
10
470
C4 C5 C12 C14 :c
850
800
900
750
950
700
1000
double
Current1
L1
12V
L2
C4
C5
C12
C14
double
Voltage
f(x) = 0
0.5
double
double
Asynchronous PWM Generator
PS-Simulink Converter:1
21
18
15
12
9
6
3
0
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
Ready
72%
ode23t

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**
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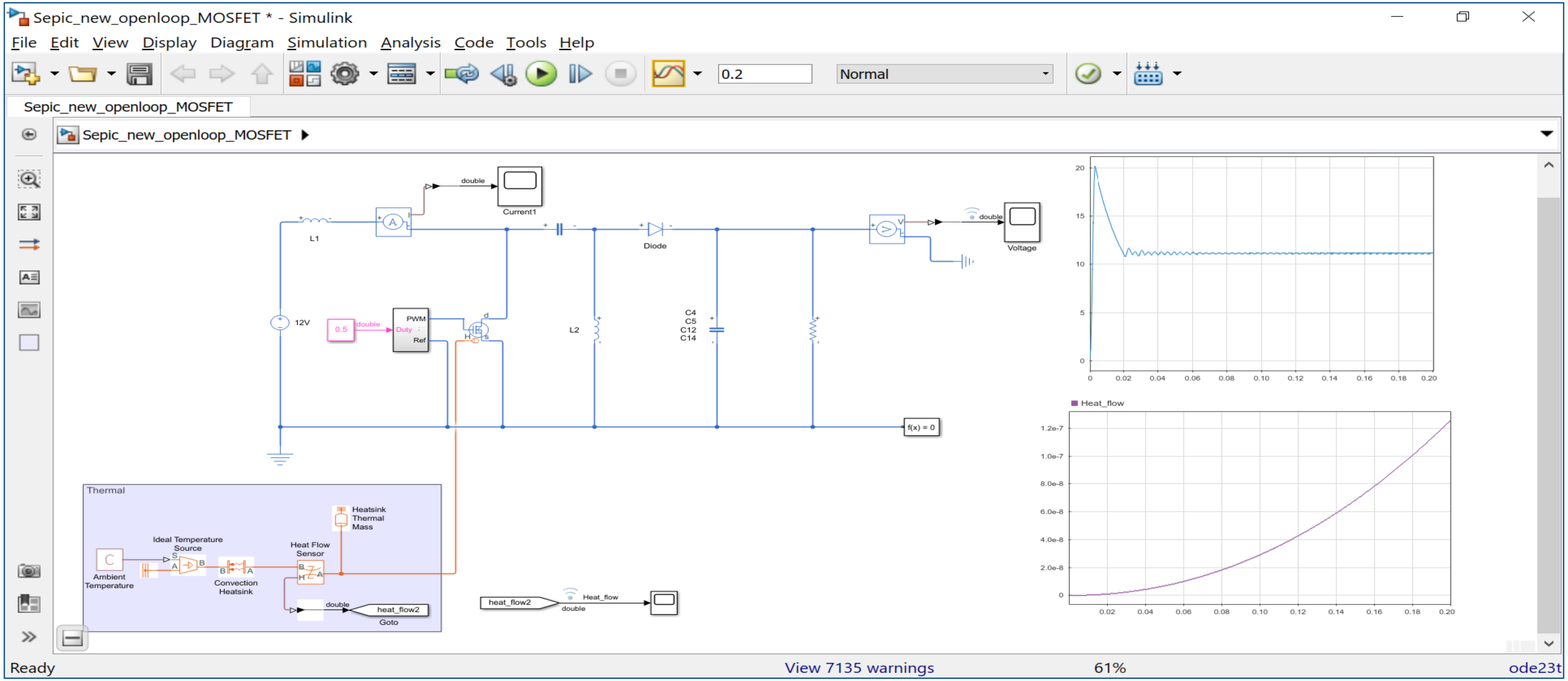
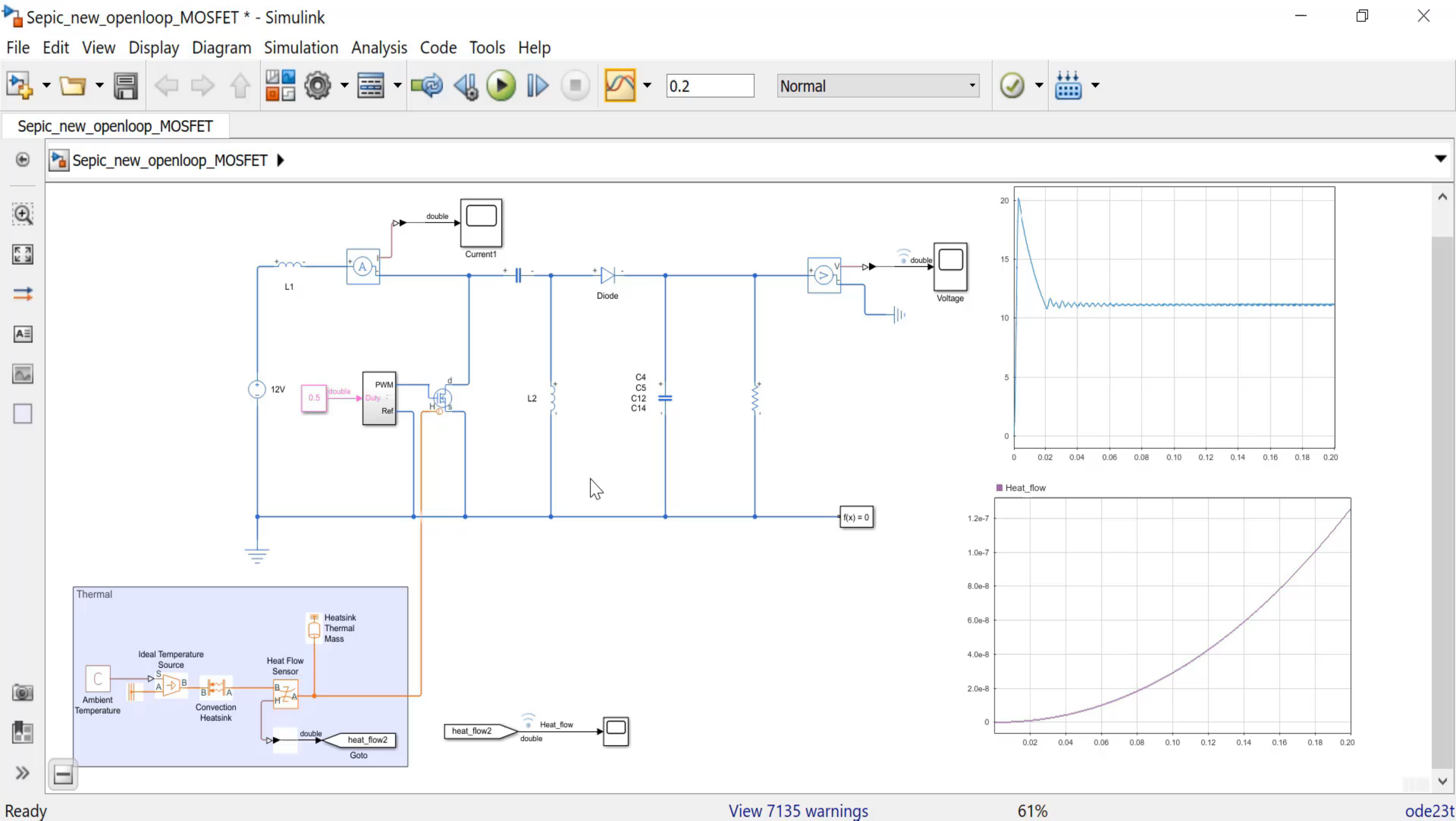
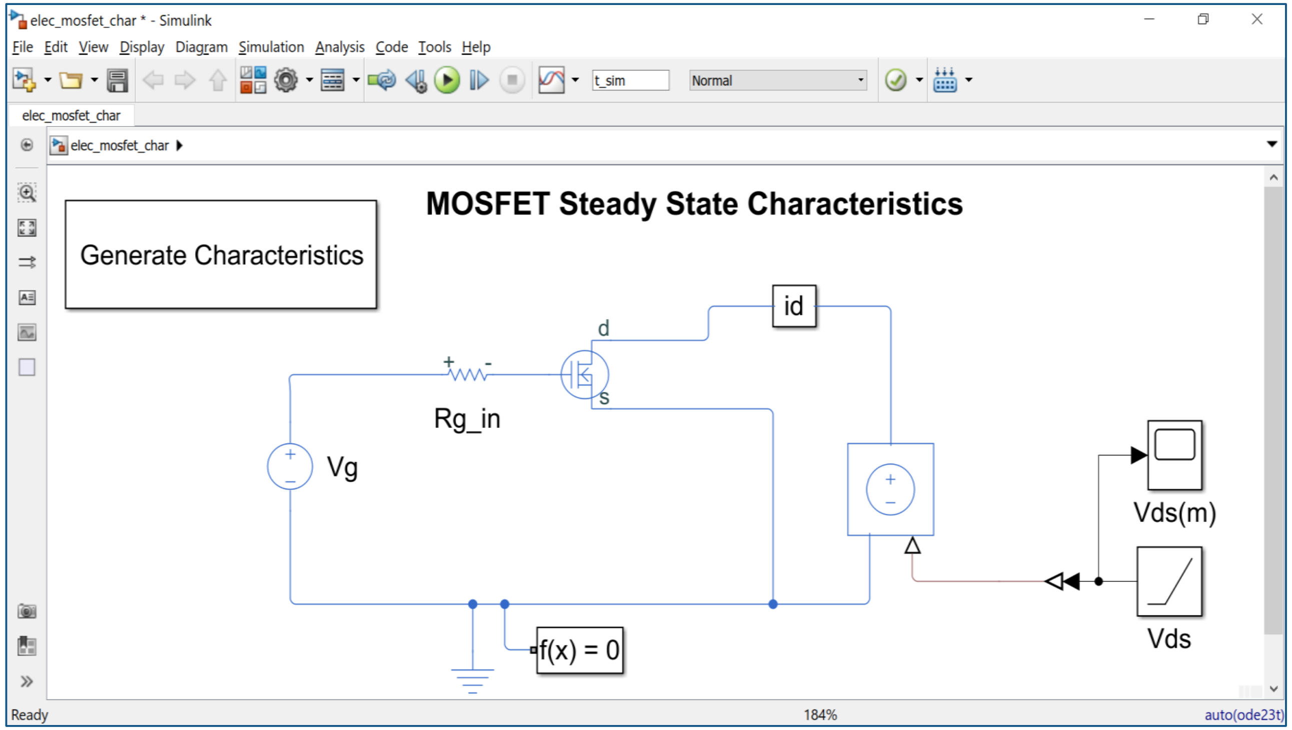
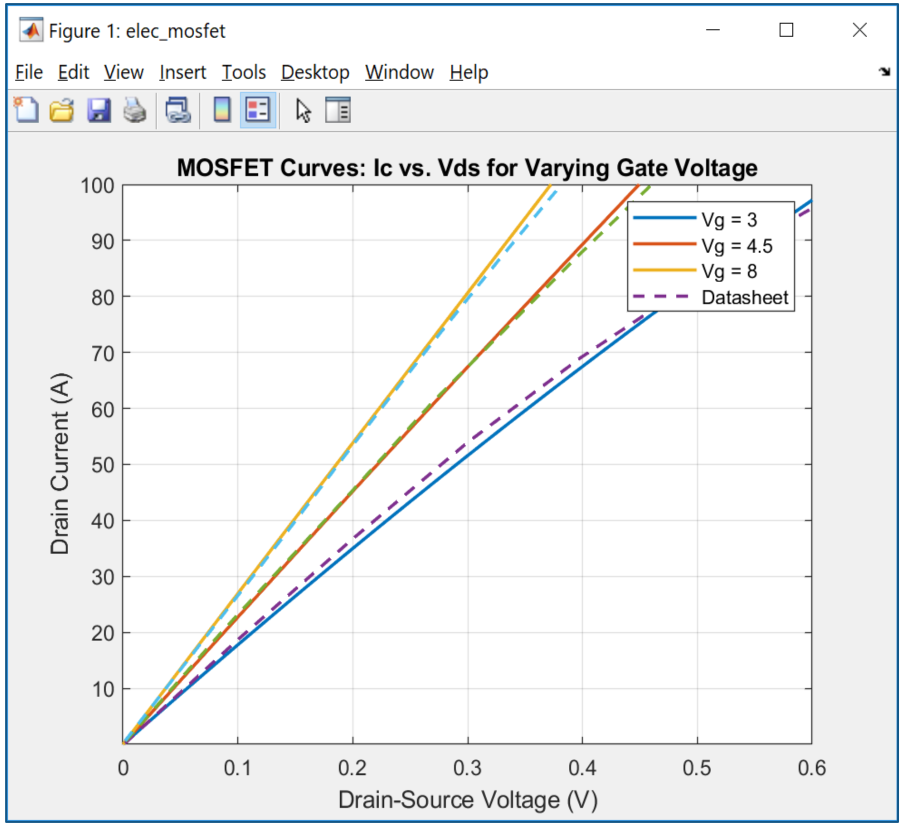
DC-DC Sepic converter with Non-Linear Switching Dynamics



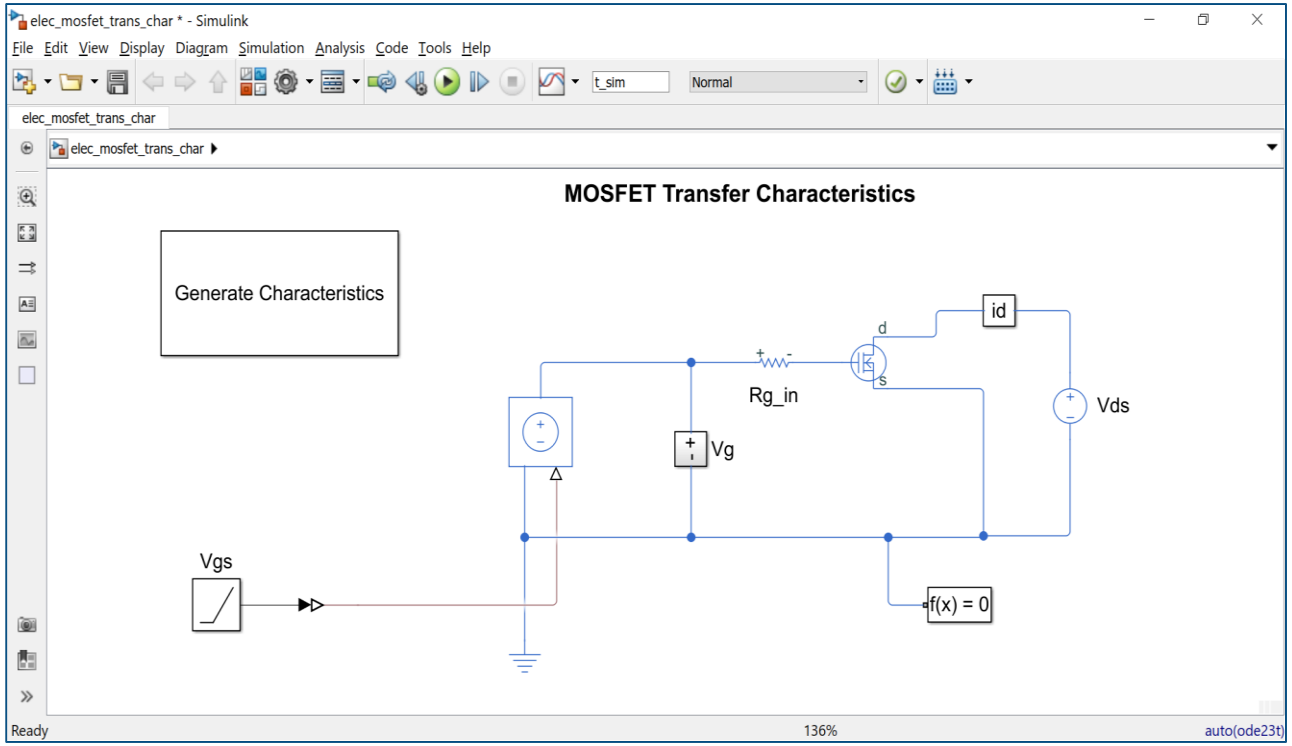

Sepic_new_openloop_MOSFET * - Simulink
File Edit View Display Diagram Simulation Analysis Code Tools Help
0.2
Normal
Sepic_new_openloop_MOSFET
double
Current1
L1
Diode
double
Voltage
12V
0.5
double
PWM
Duty
Ref
L2
C4
C5
C12
C14
f(x) = 0
Thermal
Heatsink Thermal Mass
Ideal Temperature Source
Heat Flow Sensor
Ambient Temperature
Convection Heatsink
double
heat_flow2
Goto
heat_flow2
Heat_flow
double
Heat_flow
Ready
View 7135 warnings
61%
ode23t

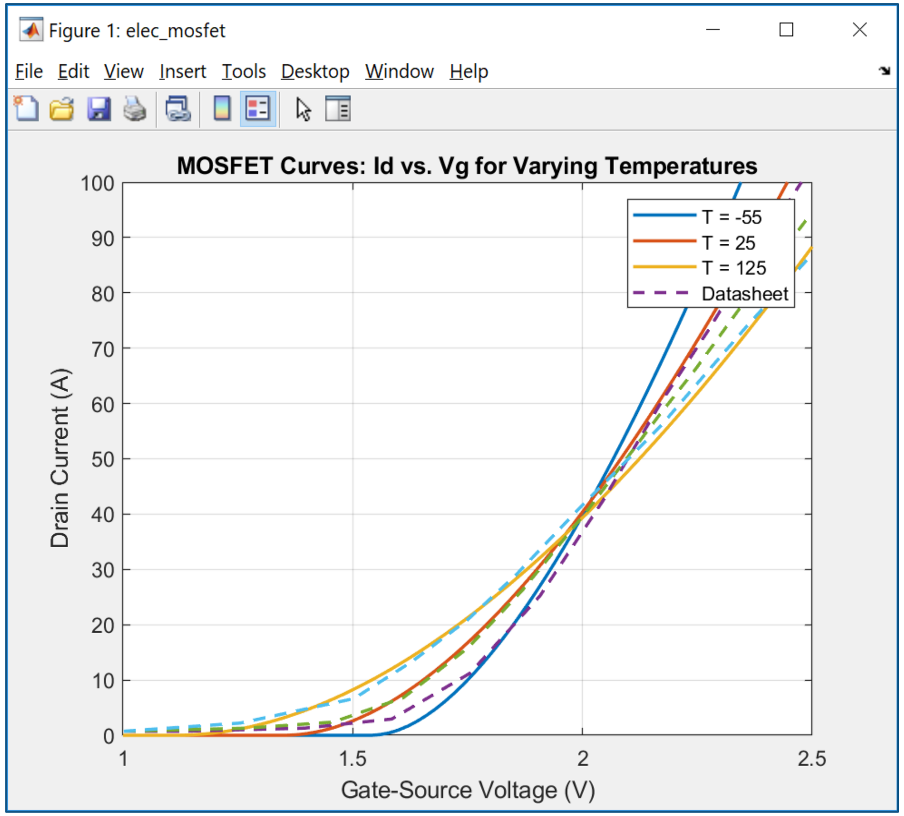
Comparison of N-Channel MOSFET Characteristics With Datasheet

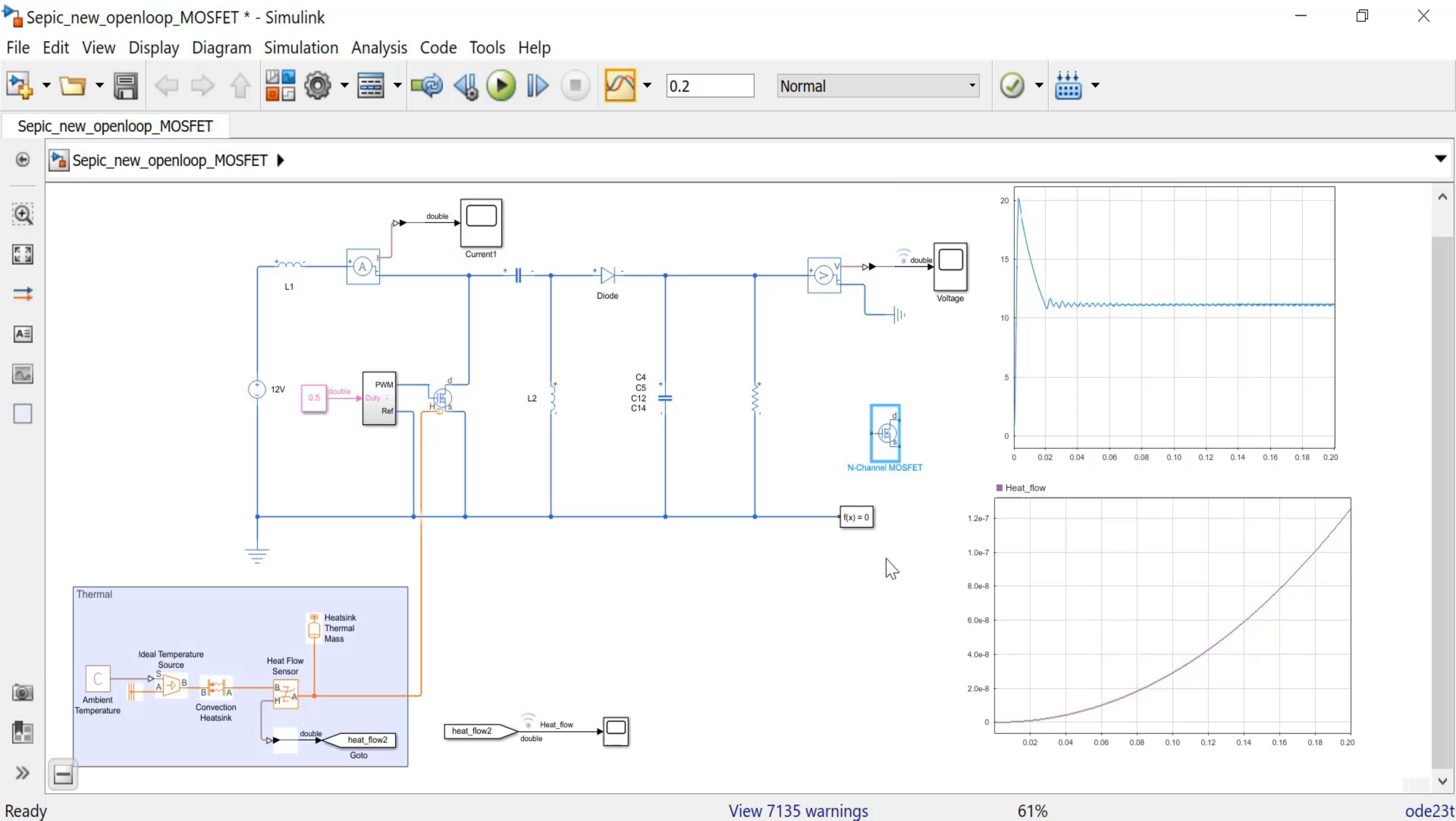




Comparison of N-Channel MOSFET Characteristics With Datasheet

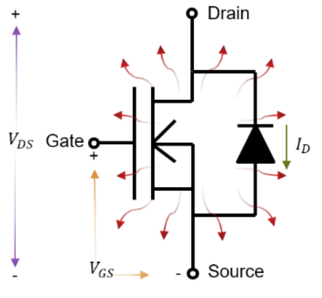




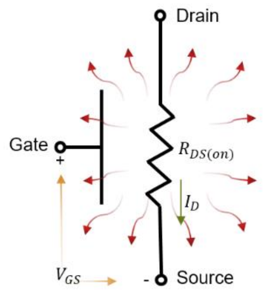


Sepic_new_openloop_MOSFET * - Simulink
File Edit View Display Diagram Simulation Analysis Code Tools Help
0.2
Normal
Sepic_new_openloop_MOSFET
Sepic_new_openloop_MOSFET
double
Current1
L1
Diode
double
Voltage
12V
0.5
double
PWM
Duty
Ref
L2
C4
C5
C12
C14
N-Channel MOSFET
f(x) = 0
Thermal
Heatsink
Thermal
Mass
Ideal Temperature
Source
Heat Flow
Sensor
Ambient
Temperature
Convection
Heatsink
double
heat_flow2
Goto
heat_flow2
Heat_flow
double
Heat_flow
Ready
View 7135 warnings
61%
ode23t

Recap: Determine Power Losses and Simulate Thermal Behaviour of the Converter.

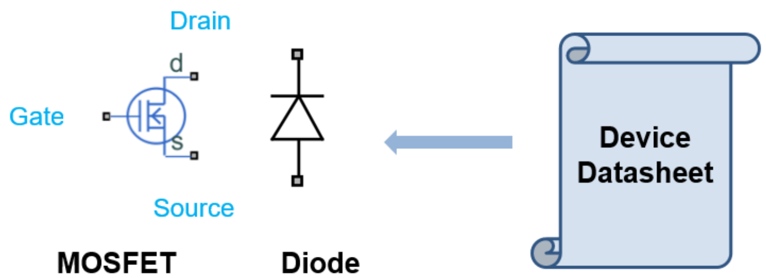


Switching loss



Conduction loss

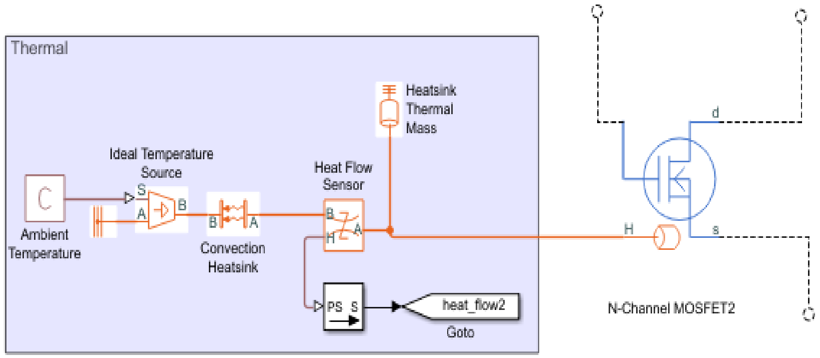
Device Blocks



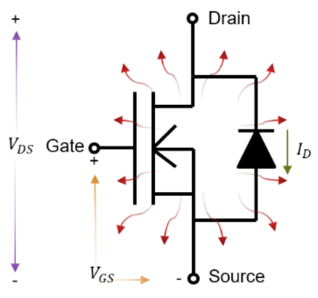
MOSFET **Diode**

What we did

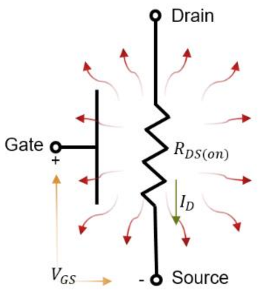
- Use semiconductor blocks from Simscape Electrical to model the non-linear switching behavior of SEPIC converter
- Leverage the multi-domain simulation capability of Simscape in understanding the thermal dynamics



Recap: Determine Power Losses and Simulate Thermal Behaviour of the Converter.

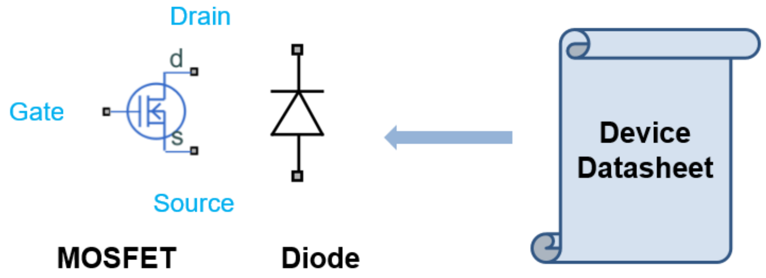


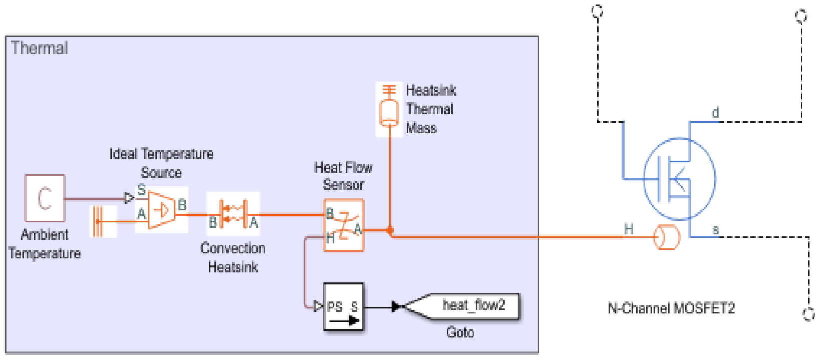
Switching loss



Conduction loss

Device Blocks





What we did

- Use semiconductor blocks from Simscape Electrical to model the non-linear switching behavior of SEPIC converter
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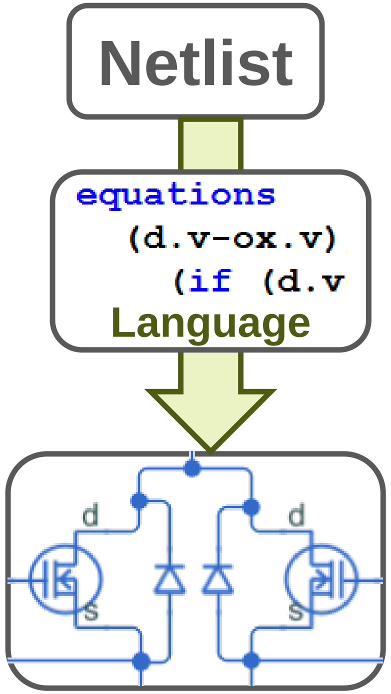
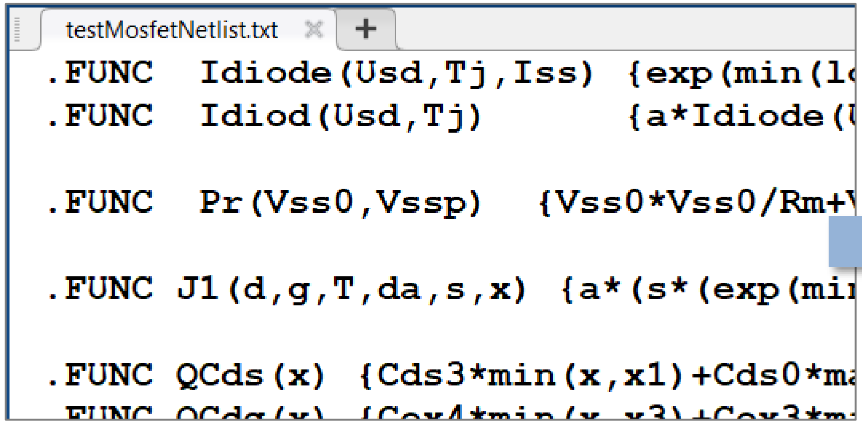
New: Convert SPICE models into Simscape components



- 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

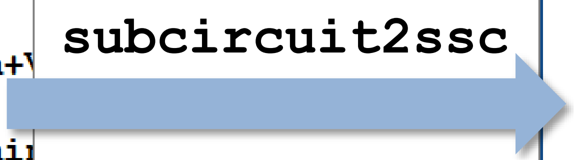


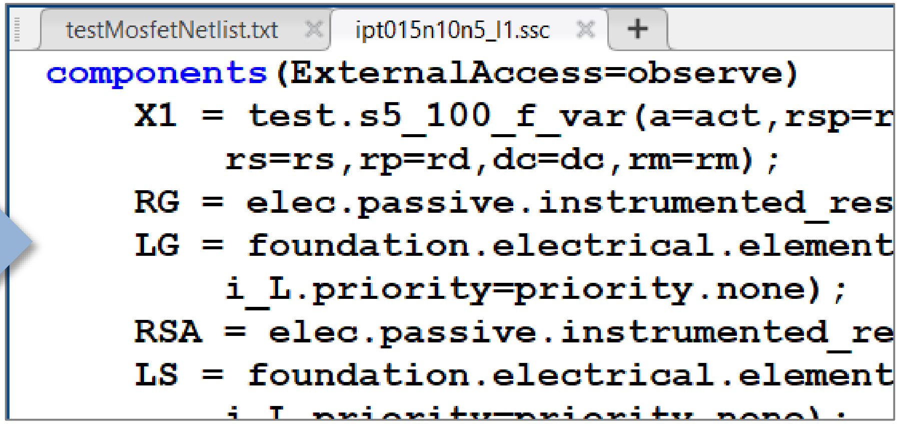

```
.FUNC  Idiode(Usd,Tj,Iss)  {exp(min(l
.FUNC  Idiod(Usd,Tj)       {a*Idiode(U

.FUNC  Pr(Vss0,Vssp)    {Vss0*Vss0/Rm+V

.FUNC J1(d,g,T,da,s,x)  {a*(s*(exp(mi

.FUNC QCds(x)  {Cds3*min(x,x1)+Cds0*ma
```






```
components(ExternalAccess=observe)
    X1 = test.s5_100_f_var(a=act,rsp=r
        rs=rs,rp=rd,dc=dc,rm=rm);
    RG = elec.passive.instrumented_res
    LG = foundation.electrical.element
        i_L.priority=priority.none);
    RSA = elec.passive.instrumented_re
    LS = foundation.electrical.element
```

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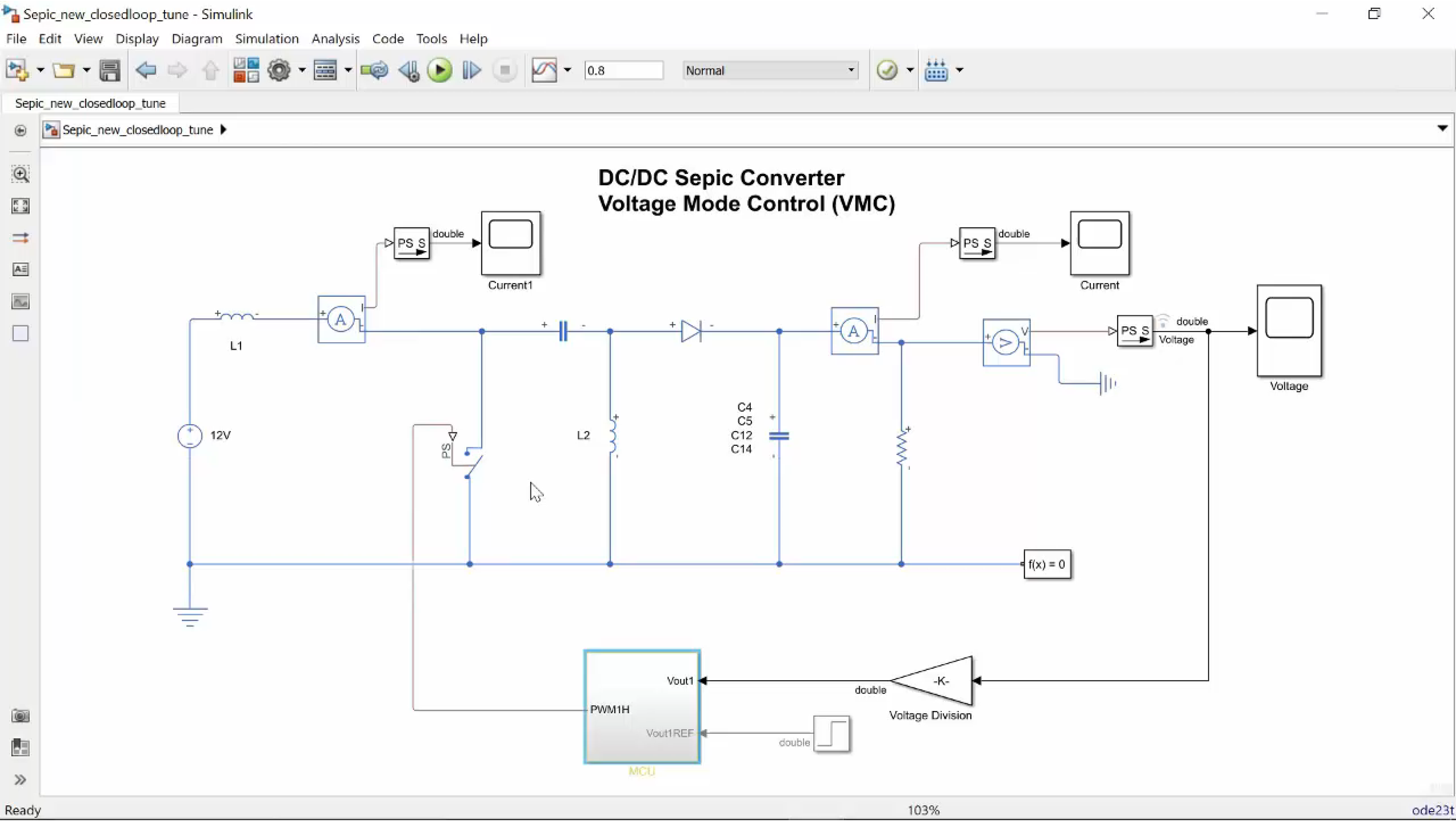
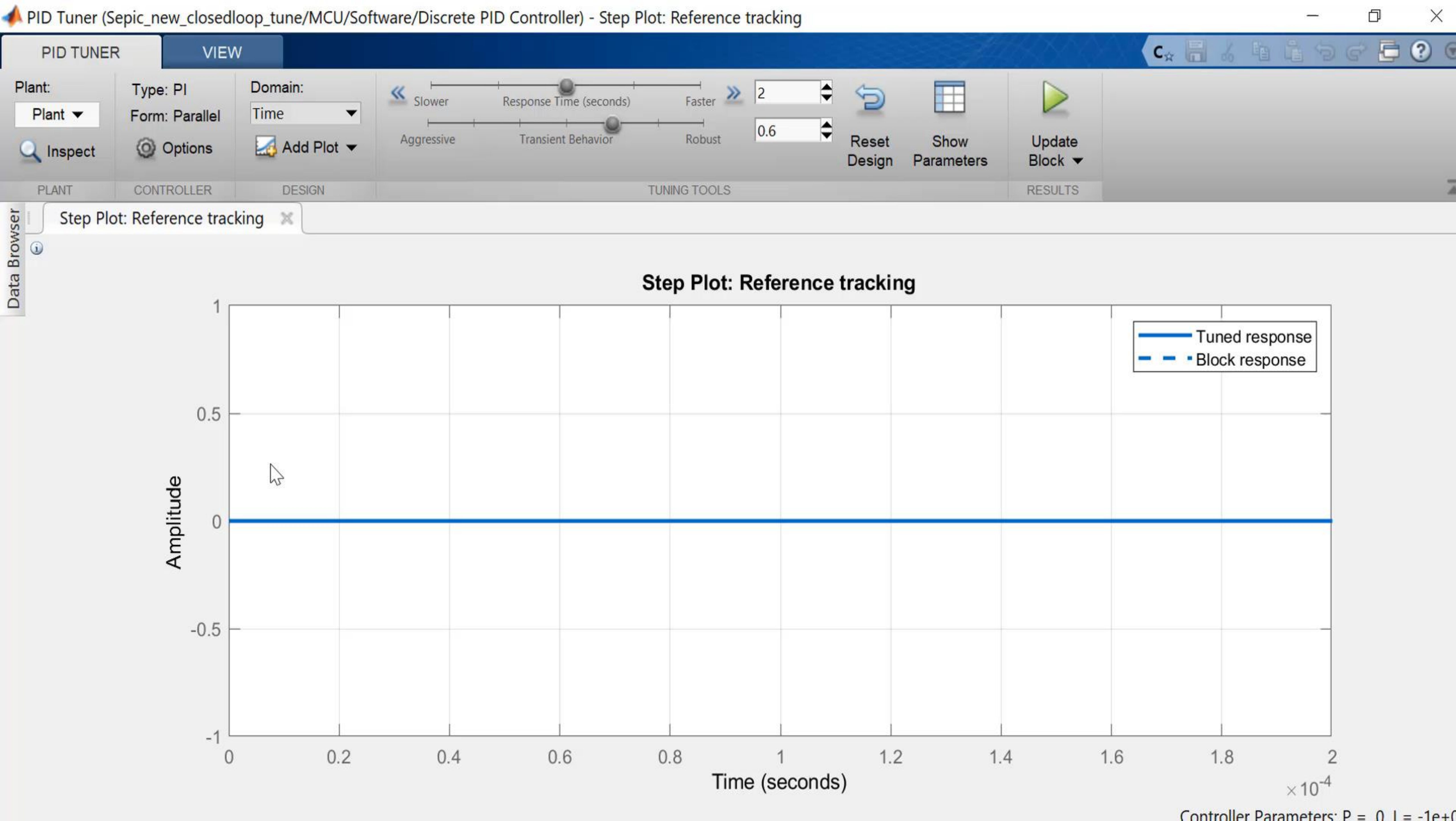
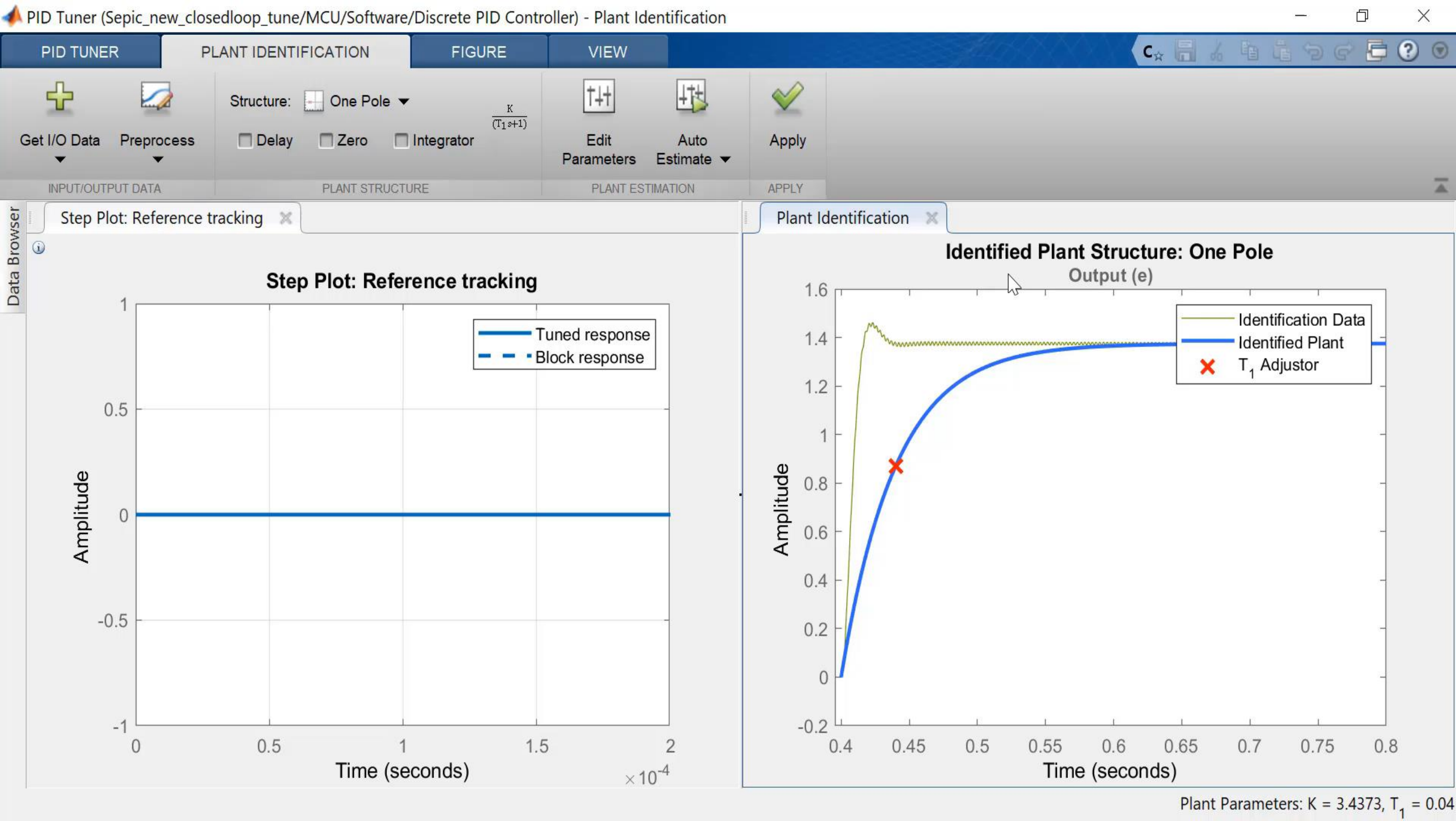
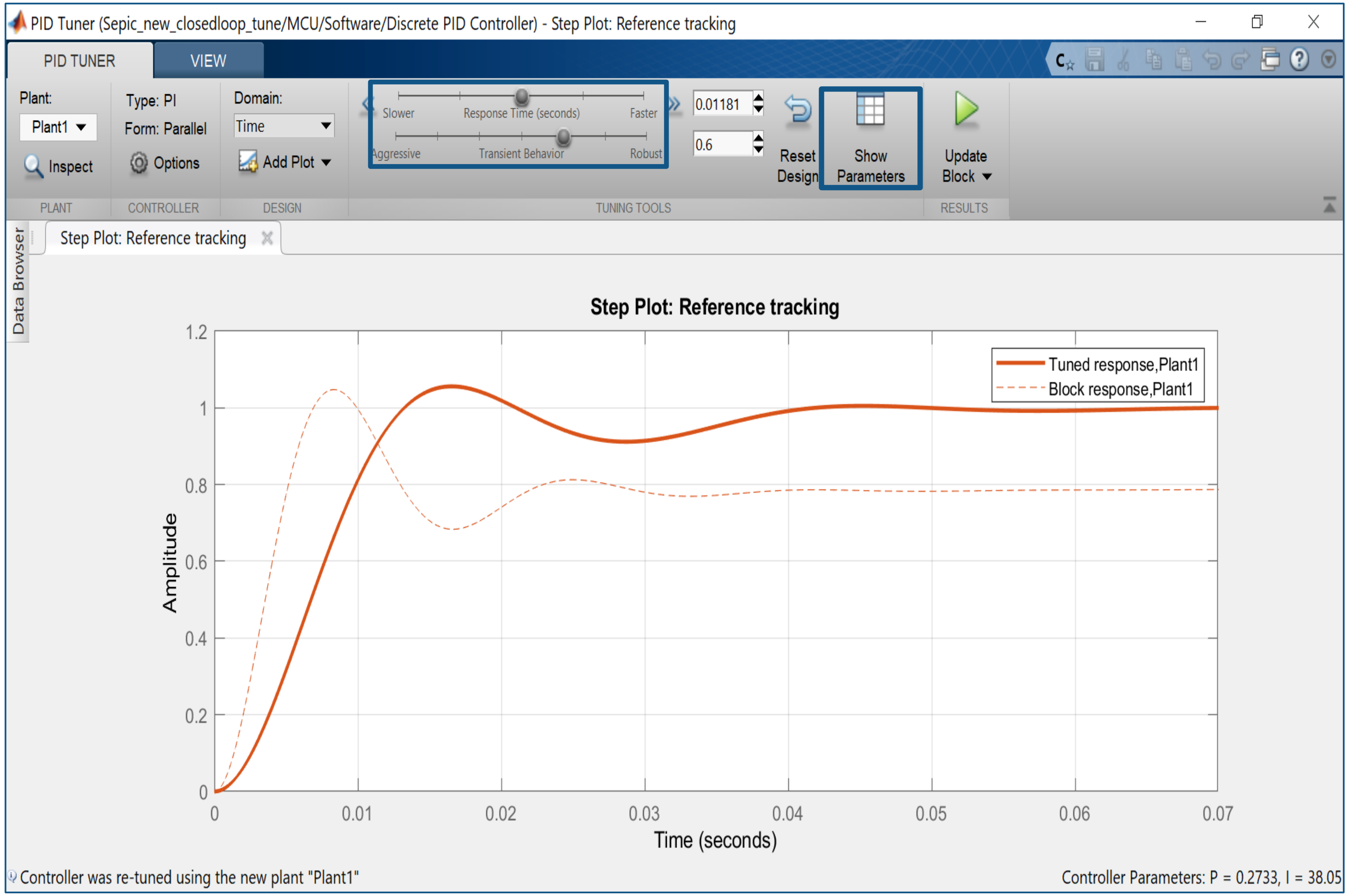

Sepic_new_closedloop_tune - Simulink
File Edit View Display Diagram Simulation Analysis Code Tools Help
0.8
Normal
Sepic_new_closedloop_tune
DC/DC Sepic Converter
Voltage Mode Control (VMC)
double
Current1
Current
Voltage
L1
L2
12V
C4
C5
C12
C14
f(x) = 0
Vout1
PWM1H
Vout1REF
MCU
-K-
Voltage Division
Ready
103%
ode23t


PID Tuner (Sepic_new_closedloop_tune/MCU/Software/Discrete PID Controller) - Step Plot: Reference tracking
PID TUNER
VIEW
Plant:
Plant
Inspect
Type: PI
Form: Parallel
Options
Domain:
Time
Add Plot
Slower
Response Time (seconds)
Faster
2
Aggressive
Transient Behavior
Robust
0.6
Reset Design
Show Parameters
Update Block
PLANT
CONTROLLER
DESIGN
TUNING TOOLS
RESULTS
Data Browser
Step Plot: Reference tracking
Step Plot: Reference tracking
Tuned response
Block response
Amplitude
1
0.5
0
-0.5
-1
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Time (seconds)
$\times 10^{-4}$
Controller Parameters: P = 0, I = -1e+0


PID Tuner (Sepic_new_closedloop_tune/MCU/Software/Discrete PID Controller) - Plant Identification
PID TUNER
PLANT IDENTIFICATION
FIGURE
VIEW
Get I/O Data
Preprocess
Structure:
One Pole
Delay
Zero
Integrator
K
(T1s+1)
Edit Parameters
Auto Estimate
Apply
INPUT/OUTPUT DATA
PLANT STRUCTURE
PLANT ESTIMATION
APPLY
Data Browser
Step Plot: Reference tracking
Step Plot: Reference tracking
Tuned response
Block response
Amplitude
1
0.5
0
-0.5
-1
0
0.5
1
1.5
2
Time (seconds)
×10^-4
Plant Identification
Identified Plant Structure: One Pole
Output (e)
Identification Data
Identified Plant
T1 Adjustor
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
Time (seconds)
Plant Parameters: K = 3.4373, T1 = 0.04

Controlling PID parameters

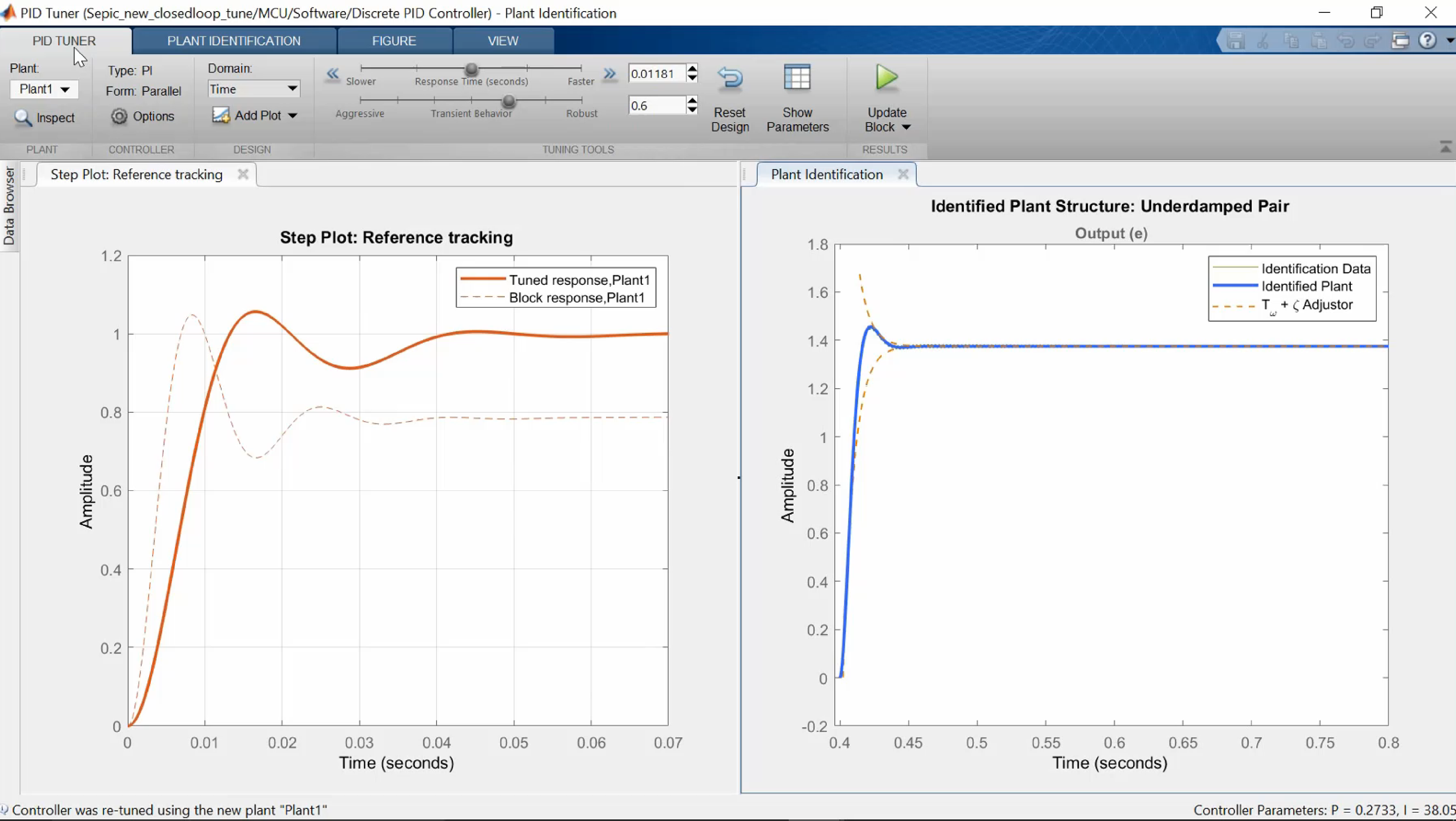


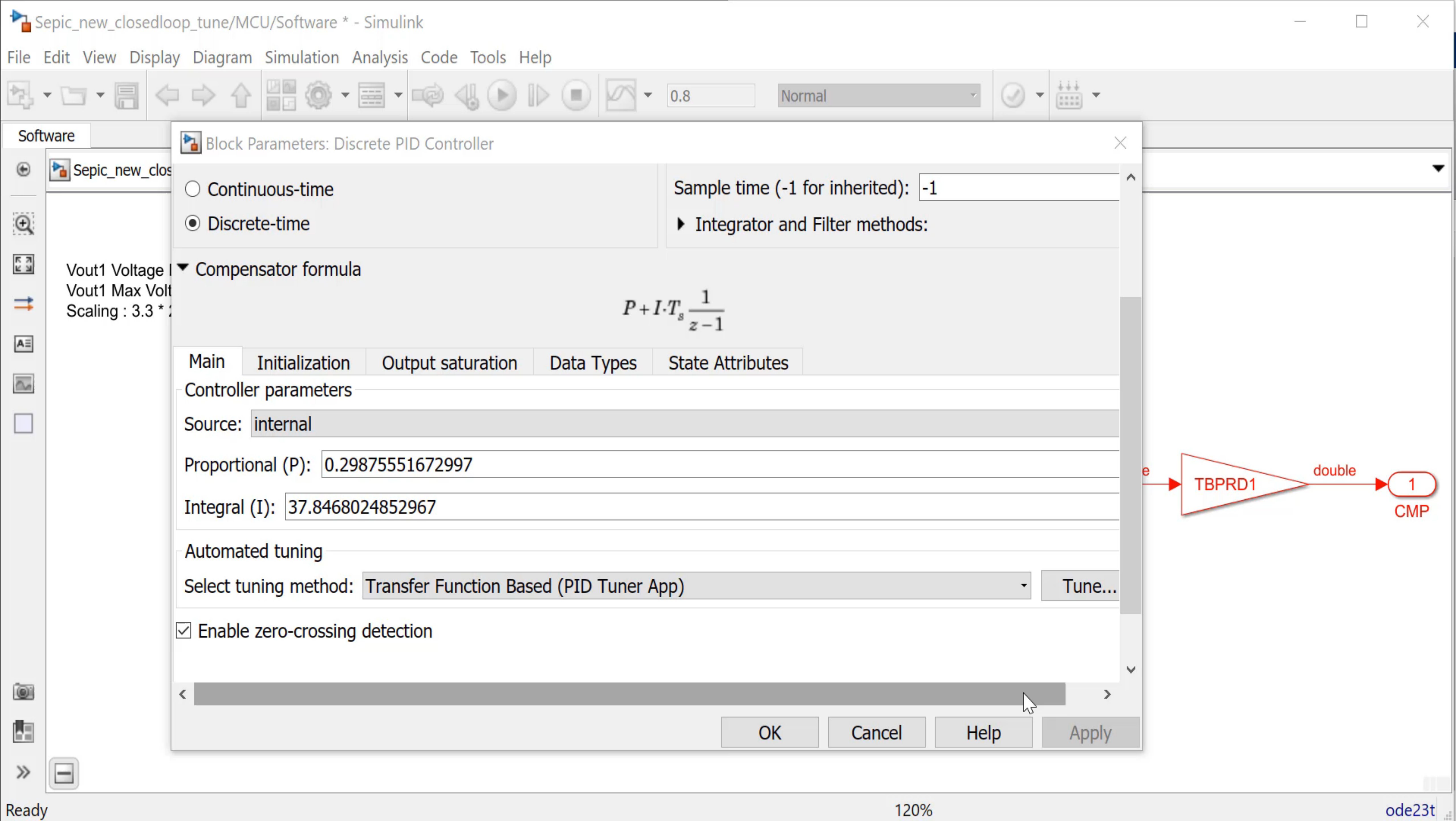
Controller Parameters

	Tuned	Block
P	0.27328	1
I	38.0456	1
D	n/a	n/a
N	n/a	n/a

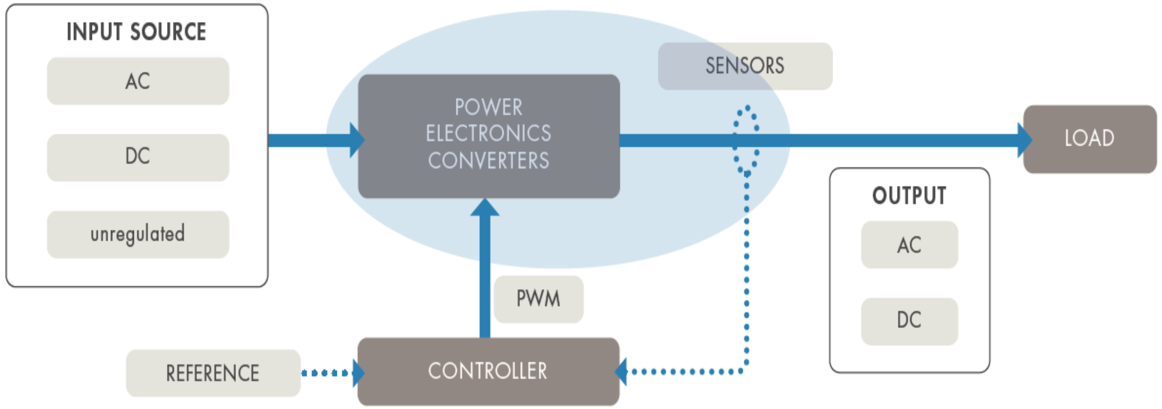
Performance and Robustness

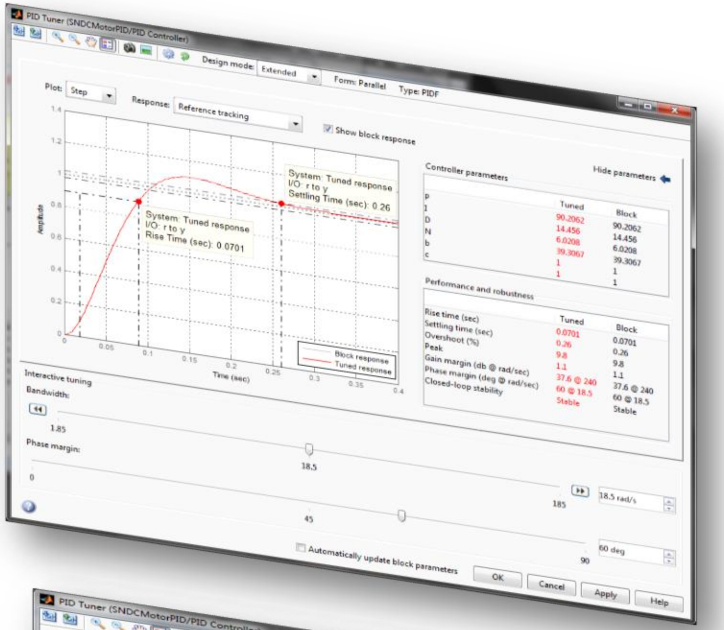
	Tuned	Block
Rise time	0.00864 seconds	0.00342 seconds
Settling time	0.0382 seconds	0.0351 seconds
Overshoot	5.6 %	32.9 %
Peak	1.06	1.05
Gain margin	147 dB @ 2.68e+05 ra...	361 dB @ 3.14e+05 r...
Phase margin	60 deg @ 169 rad/s	45.7 deg @ 349 rad/s
Closed-loop stability	Stable	Stable

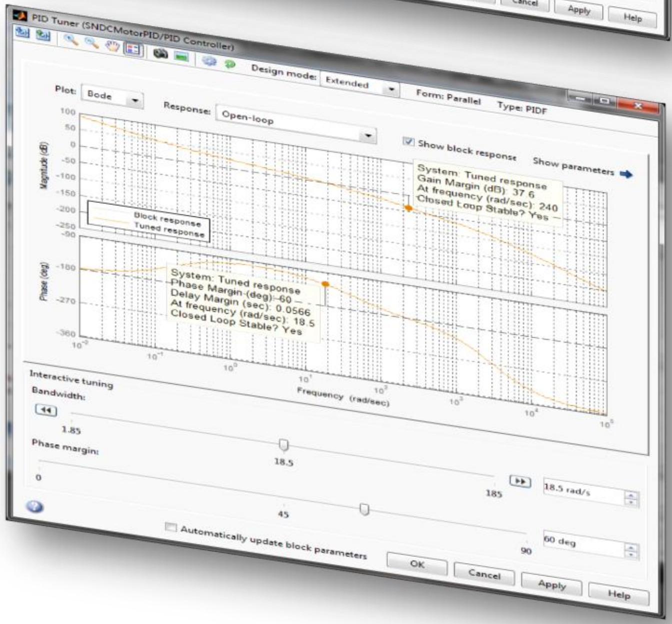

PID Tuner (Sepic_new_closedloop_tune/MCU/Software/Discrete PID Controller) - Plant Identification
PID TUNER
PLANT IDENTIFICATION
FIGURE
VIEW
Plant:
Plant1
Inspect
Type: PI
Form: Parallel
Options
Domain:
Time
Add Plot
Slower
Response Time (seconds)
Faster
0.01181
Aggressive
Transient Behavior
Robust
0.6
Reset Design
Show Parameters
Update Block
PLANT
CONTROLLER
DESIGN
TUNING TOOLS
RESULTS
Data Browser
Step Plot: Reference tracking
Plant Identification
Step Plot: Reference tracking
Tuned response,Plant1
Block response,Plant1
Amplitude
Time (seconds)
Identified Plant Structure: Underdamped Pair
Output (e)
Identification Data
Identified Plant
T + ζ Adjustor
Amplitude
Time (seconds)
Controller was re-tuned using the new plant "Plant1"
Controller Parameters: P = 0.2733, I = 38.05


Sepic_new_closedloop_tune/MCU/Software * - Simulink
File Edit View Display Diagram Simulation Analysis Code Tools Help
0.8
Normal
Software
Sepic_new_clos
Vout1 Voltage
Vout1 Max Volt
Scaling : 3.3 *
Block Parameters: Discrete PID Controller
Continuous-time
Discrete-time
Sample time (-1 for inherited): -1
Integrator and Filter methods:
Compensator formula
$P+I\cdot T_s\frac{1}{z-1}$
Main
Initialization
Output saturation
Data Types
State Attributes
Controller parameters
Source: internal
Proportional (P): 0.29875551672997
Integral (I): 37.8468024852967
Automated tuning
Select tuning method: Transfer Function Based (PID Tuner App)
Tune...
Enable zero-crossing detection
OK
Cancel
Help
Apply
TBPRD1
double
1
CMP
Ready
120%
ode23t

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







What we did

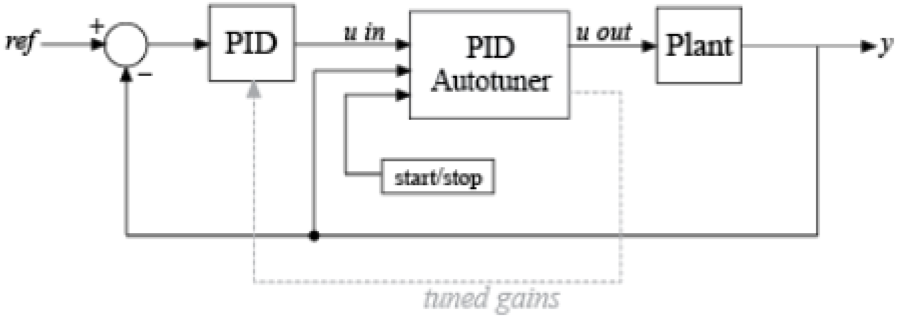
- Identify plant model from input output simulation data
- Use auto tuning algorithms to tune the control gains

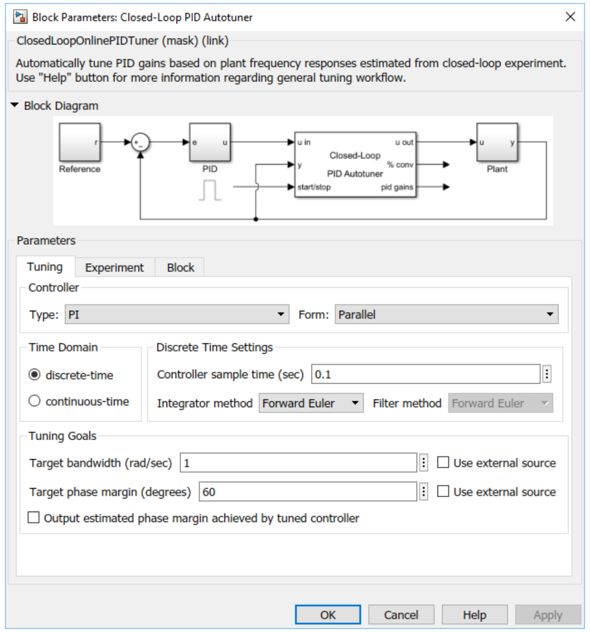
New: Autotune PID Controllers in Simulation or on Hardware

- Use Closed-Loop PID Autotuner block to generate autotuning code and deploy to embedded software

- Estimation experiment is performed without opening the feedback loop

- Use to tune PID controller gains for a plant model in Simulink or for a physical plant

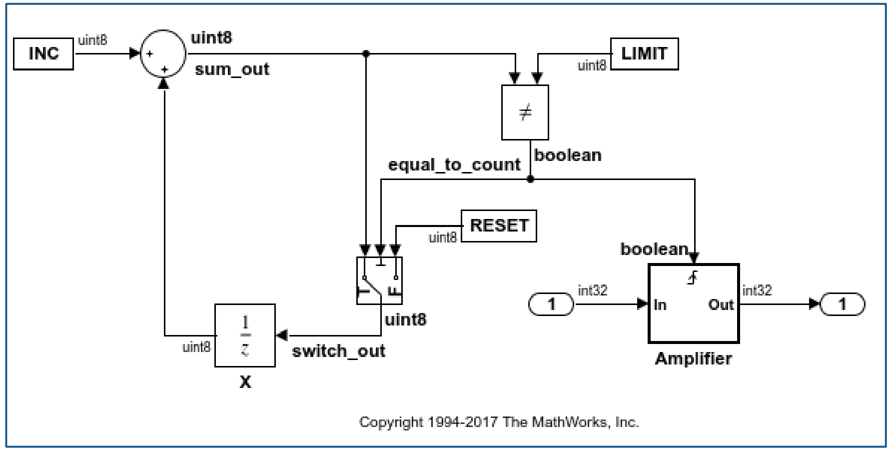




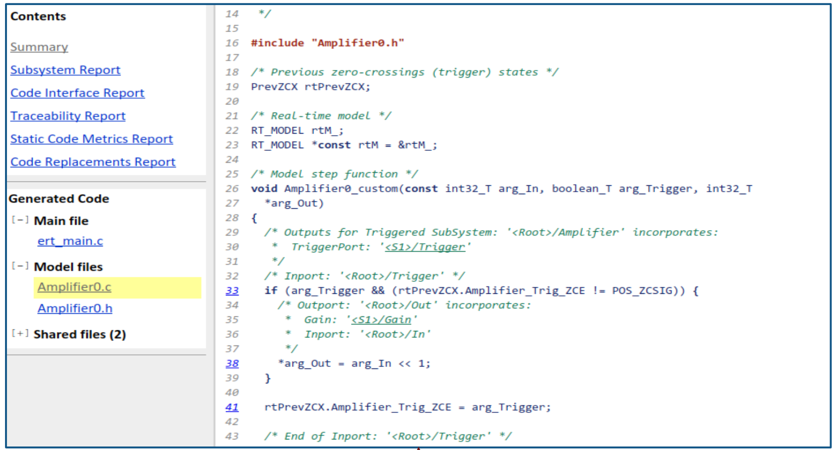
Power Converter Control Design Workflow Tasks

- 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 processor**

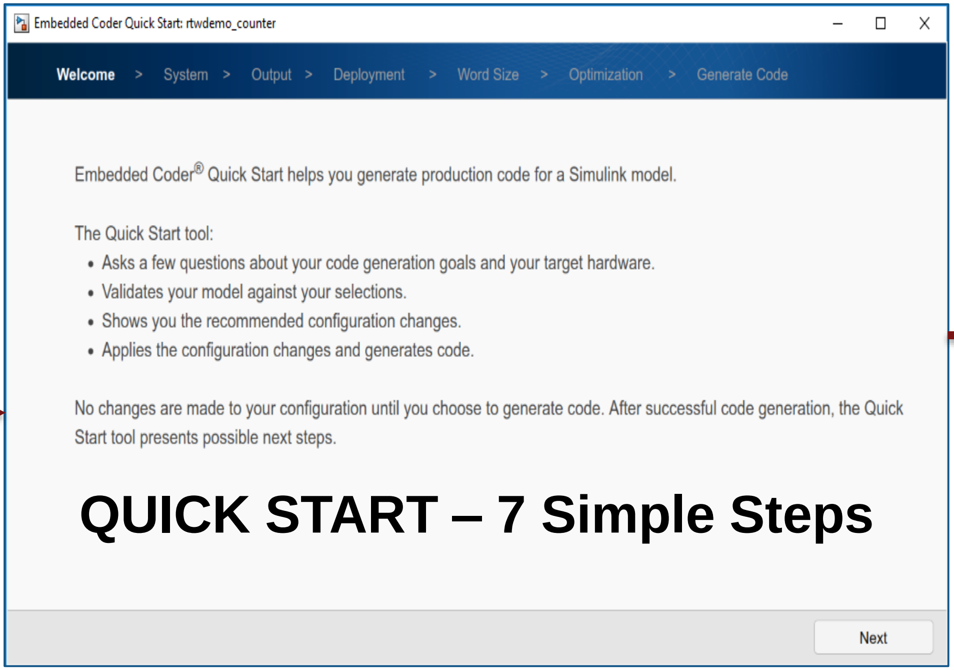
Fast Code Generation Using Embedded Coder Quick Start



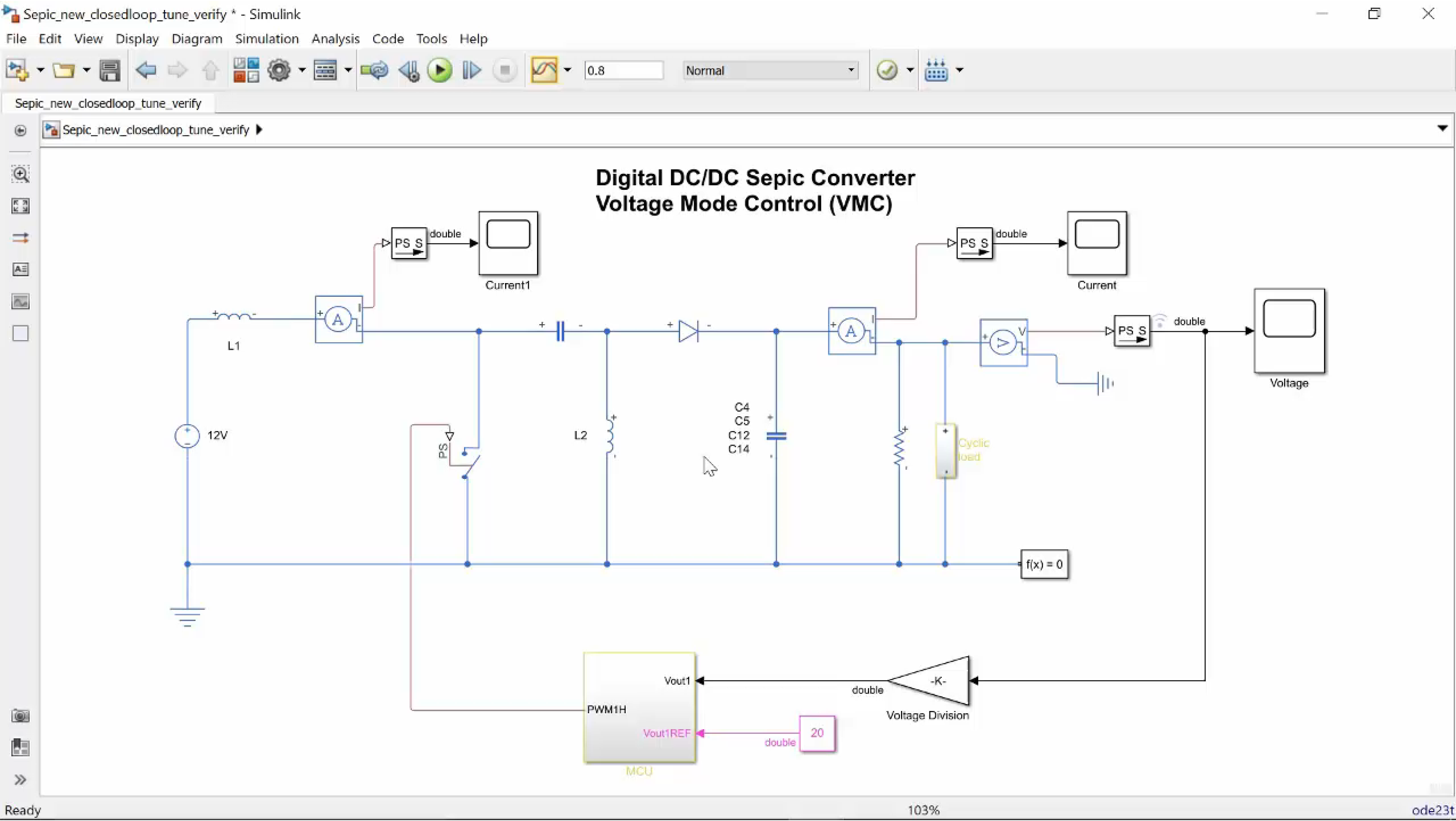
SIMULINK MODEL



GENERATED CODE



QUICK START – 7 Simple Steps


Sepic_new_closedloop_tune_verify * - Simulink
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Sepic_new_closedloop_tune_verify
Digital DC/DC Sepic Converter
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PS S
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C4
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Diagnostic Viewer

Diagnostics

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Code Generation Report

Find: Match Case

Contents

Summary

Subsystem Report

Code Interface Report

Traceability Report

Static Code Metrics Report

Code Replacements Report

Generated Code

[-] **Main file**

ert_main.c

[-] **Model files**

DC_DC_LED_External_2.c

DC_DC_LED_External_2.h

[+] **Shared files (1)**

[+] **Interface files (1)**

[+] **Other files (6)**

Code Generation Report for 'DC_DC_LED_External_2'

Model Information

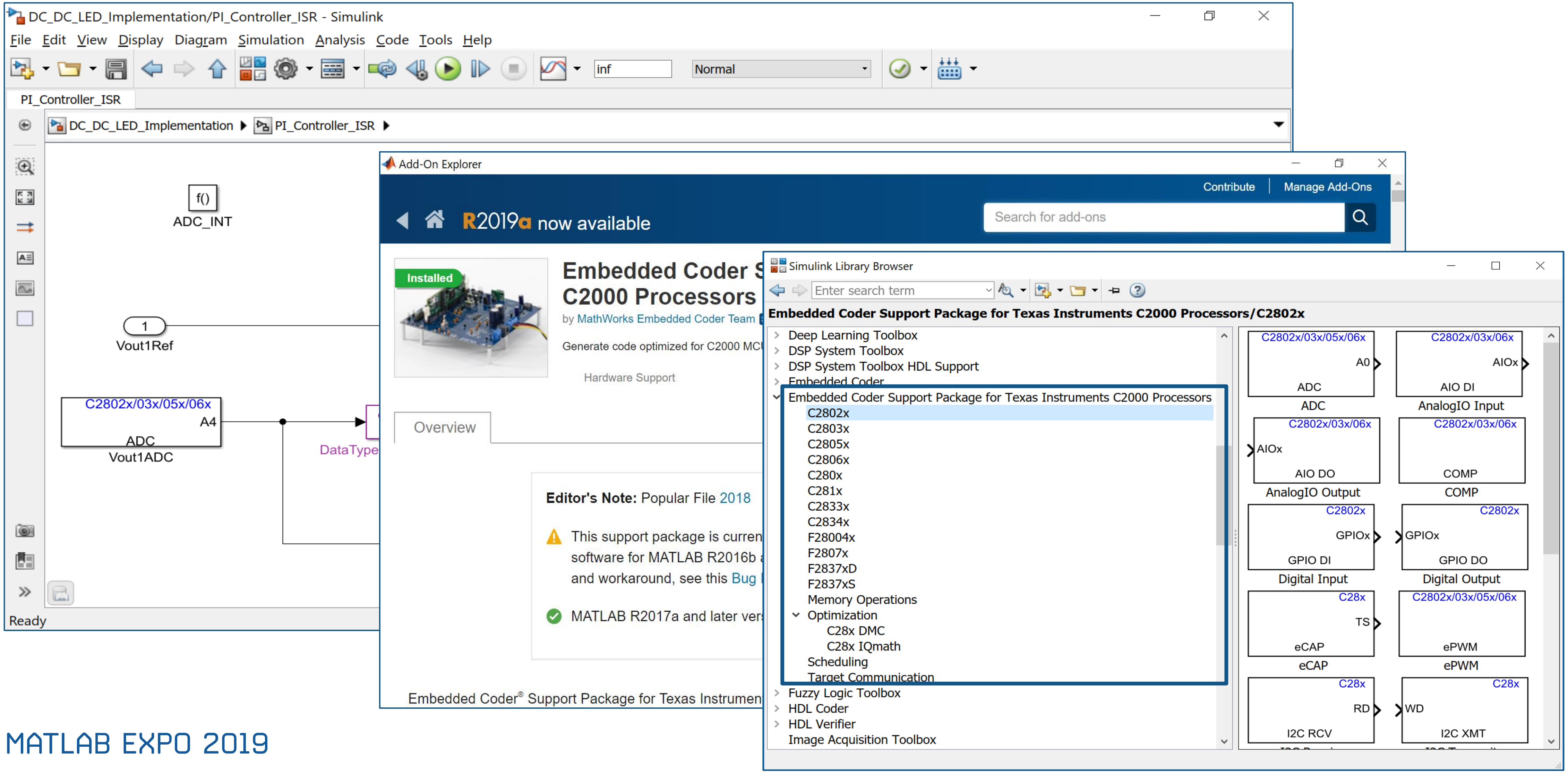
Author	vivekr
Last Modified By	vivekr
Model Version	1.252
Tasking Mode	MultiTasking

Configuration settings at time of code generation

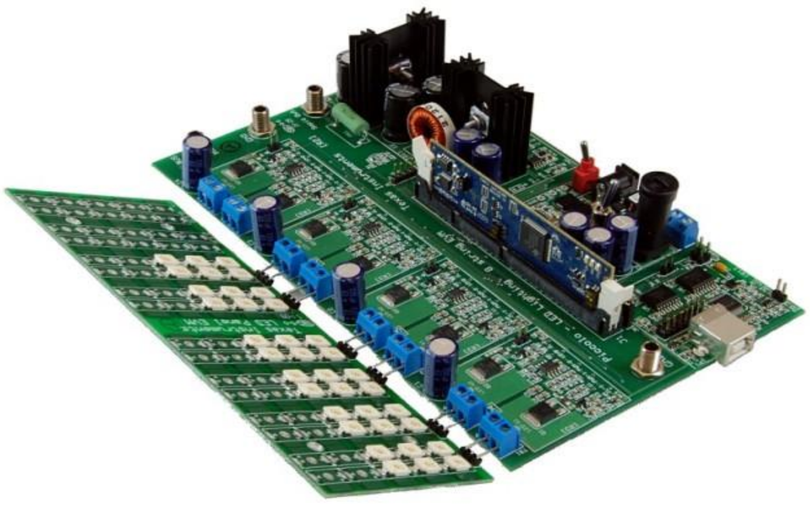
Code Information

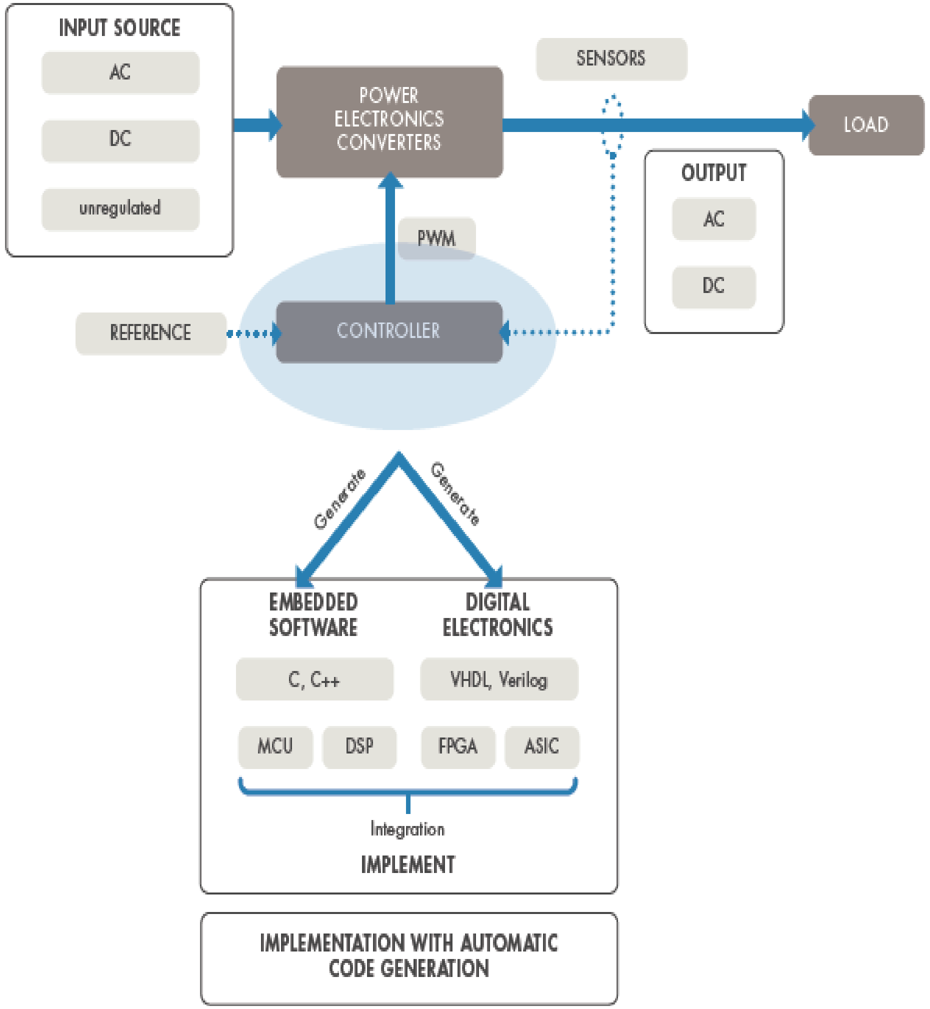
System Target File	ert.tlc
Hardware Device Type	Texas Instruments->C2000
Simulink Coder Version	8.14 (R2018a) 06-Feb-2018
Timestamp of Generated Source Code	Thu Jul 12 18:43:08 2018
Location of Generated Source Code	C:\Users\vivekr\Desktop\DC_DC_LED_External_2_ert_rtw\
Type of Build	Model
Objectives Specified	Execution efficiency, RAM efficiency, ROM efficiency

Control Algorithm deployment to TI controller and Parameter Tuning using External Mode



Recap: Implement Power Electronics Control on an Embedded Processor





What we did:

- Verify the controller for various test cases
- Generate code from MATLAB and Simulink models optimized for embedded controllers

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 processor

How We Addressed The Challenges

- Understand the impact of the power source and load
- Testing for a complete range of operating and fault conditions

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

✓ **Determine non linear switching and the thermal behavior of the converter**

- Designing and implementing digital controls using *only* SPICE simulator tools

✓ **Design control algorithm based on time/frequency domain specification**

- Catching errors during software-hardware integration testing
- Compliance to industry standards
- Development Time

✓ **Implement power electronic controls on an embedded processor**

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

Murata Used Simulink to Model the EMS Controller and Power Electronics, Run simulations, and Generate Production Code

Challenge

Reduce time-to-market for the company's first energy management system product trial

Solution

Use Model-Based Design with Simulink to model the controller and power electronics, run simulations, and generate production code implemented on Piccolo™ and Delfino™ 32-bit microcontrollers made by TI

Results

- Control software development time reduced by more than 50%
- Defect-free code generated
- Project ramp-up time shortened

Murata flexible three-phase energy management system with lithium-ion battery.

Model-Based Design with Simulink enabled us to reduce time-to-market, which was a significant advantage for us. Because we were not expert programmers, modeling and simulating our control design and then generating quality C code from our models was essential to produce a working system as quickly as possible."

- Dr. Yue Ma, Murata Manufacturing Co., Ltd.

Maggiori Informazioni

- Partecipate alla masterclass
  "Sviluppo di un sistema di gestione delle batterie con Simulink»
- Visitate la pagina mathworks.com/solutions/power-electronics-control
- Scaricate power electronics control design trial package con il software necessario per effettuare desktop modeling, simulazione e control design