MATLAB EXPO 2019

Developing and Implementing Digital Control for Power Converters

Naini Dawar

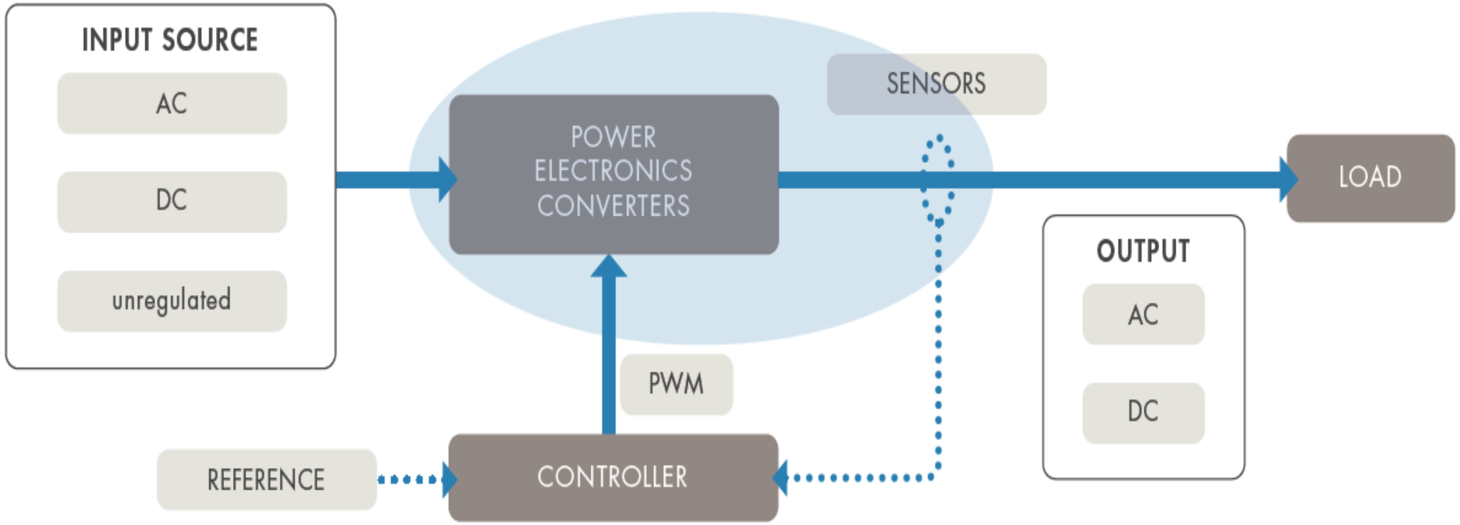
Electric vehicles and charging stations

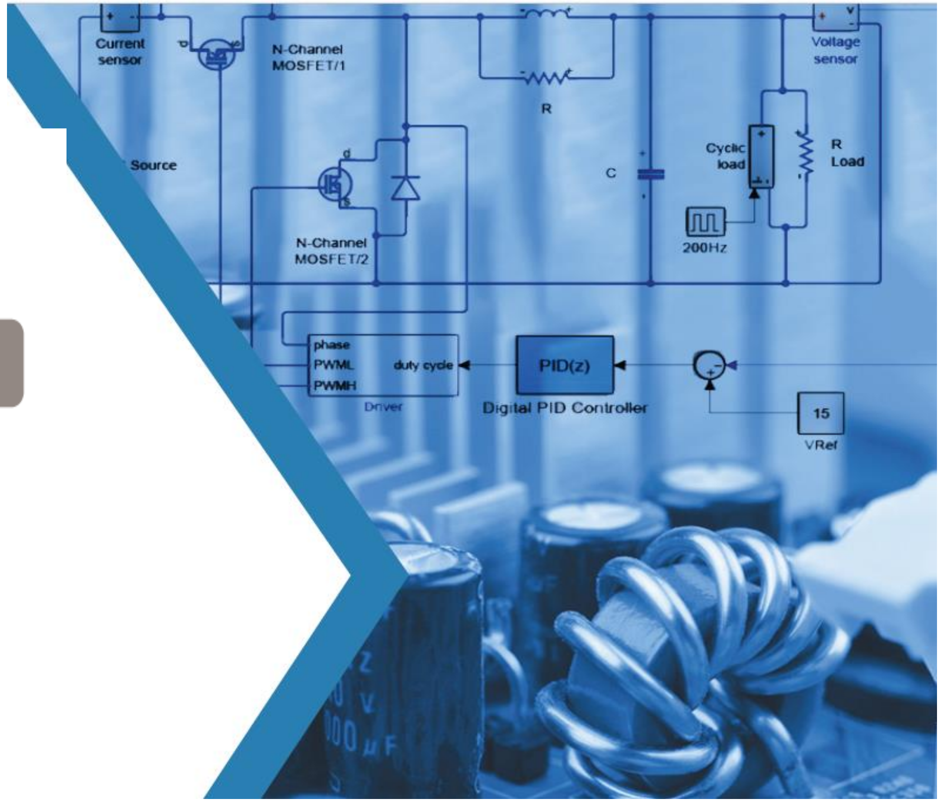
Rail

Renewable energy

Lighting

Power Electronic Systems





Our Project Today

DC/DC LED Developer's Kit

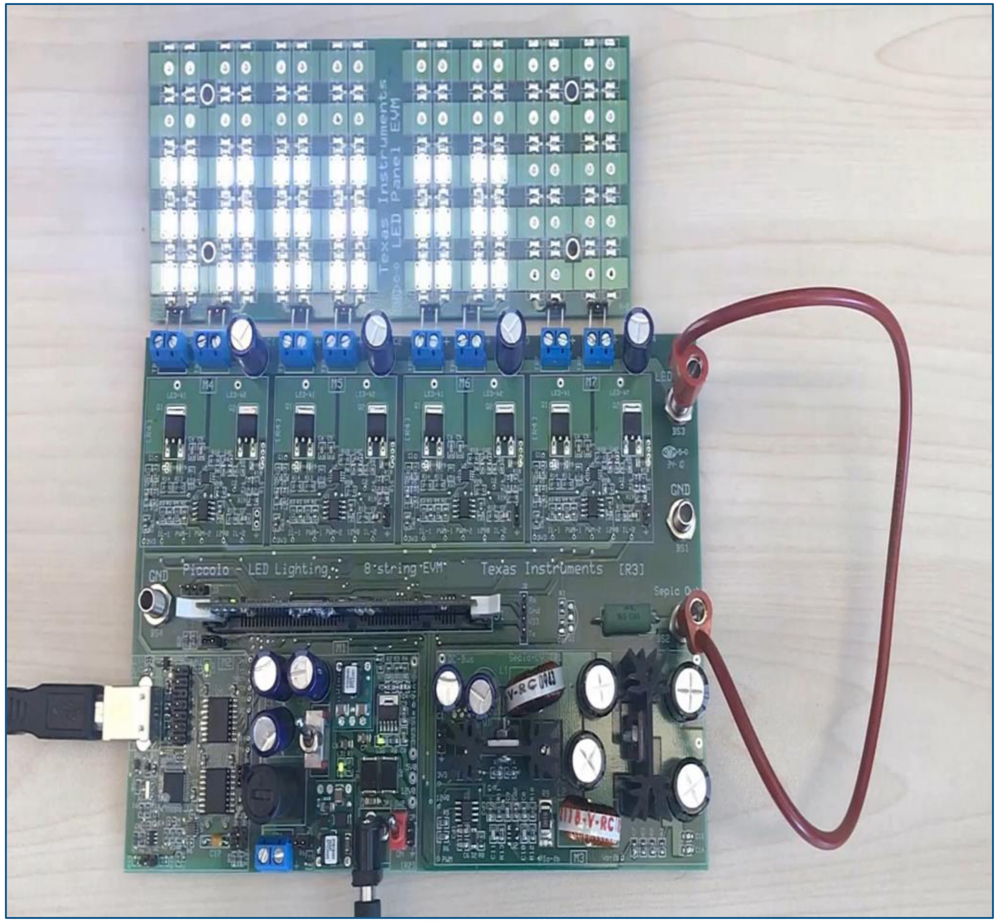


Fig 1: TMDSDCDCLEDKIT

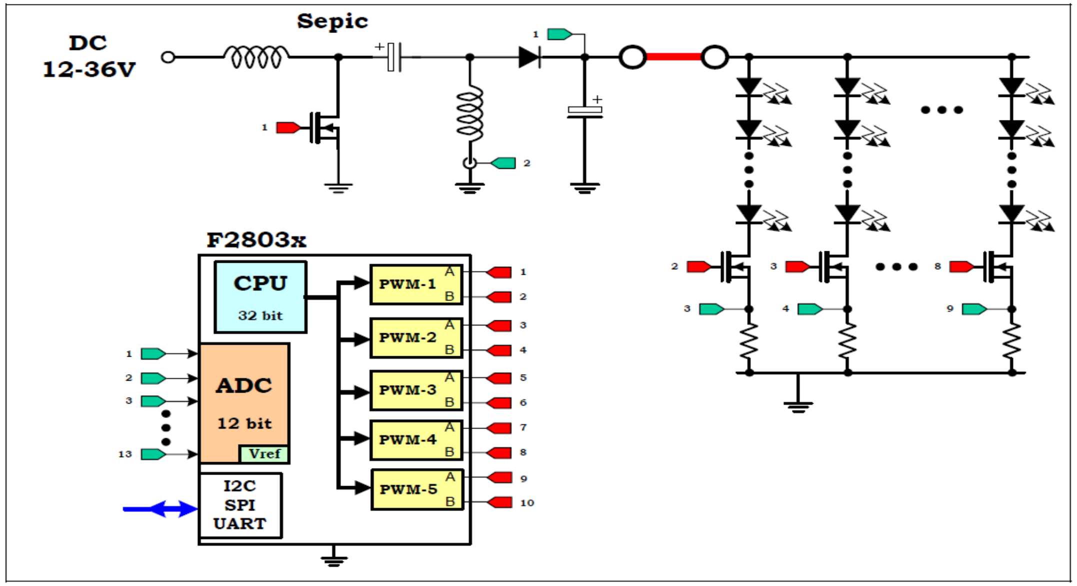


Fig4: DC/DC LED Lighting Board Block diagram with F28035

Challenges for Power Electronics Engineer

- Understand the impact of the power source and load
- Testing for a complete range of operating and fault conditions
- Designing and implementing digital controls using *only* SPICE simulator tools
- Catching errors during software-hardware integration testing
- Compliance to industry standards
- Development Time

Power Converter Control Design Workflow Tasks

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

2. Determine non linear switching and the thermal behavior of the converter

3. Design control algorithm based on time/frequency domain specification

4. Implement power electronic controls on an embedded processor

Let’s get to it!

Power Converter Control Design Workflow Tasks

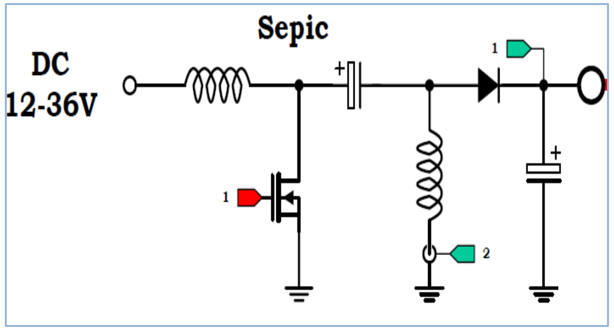
- **Size inductor, capacitor and understand the behaviour in continuous and discontinuous mode**

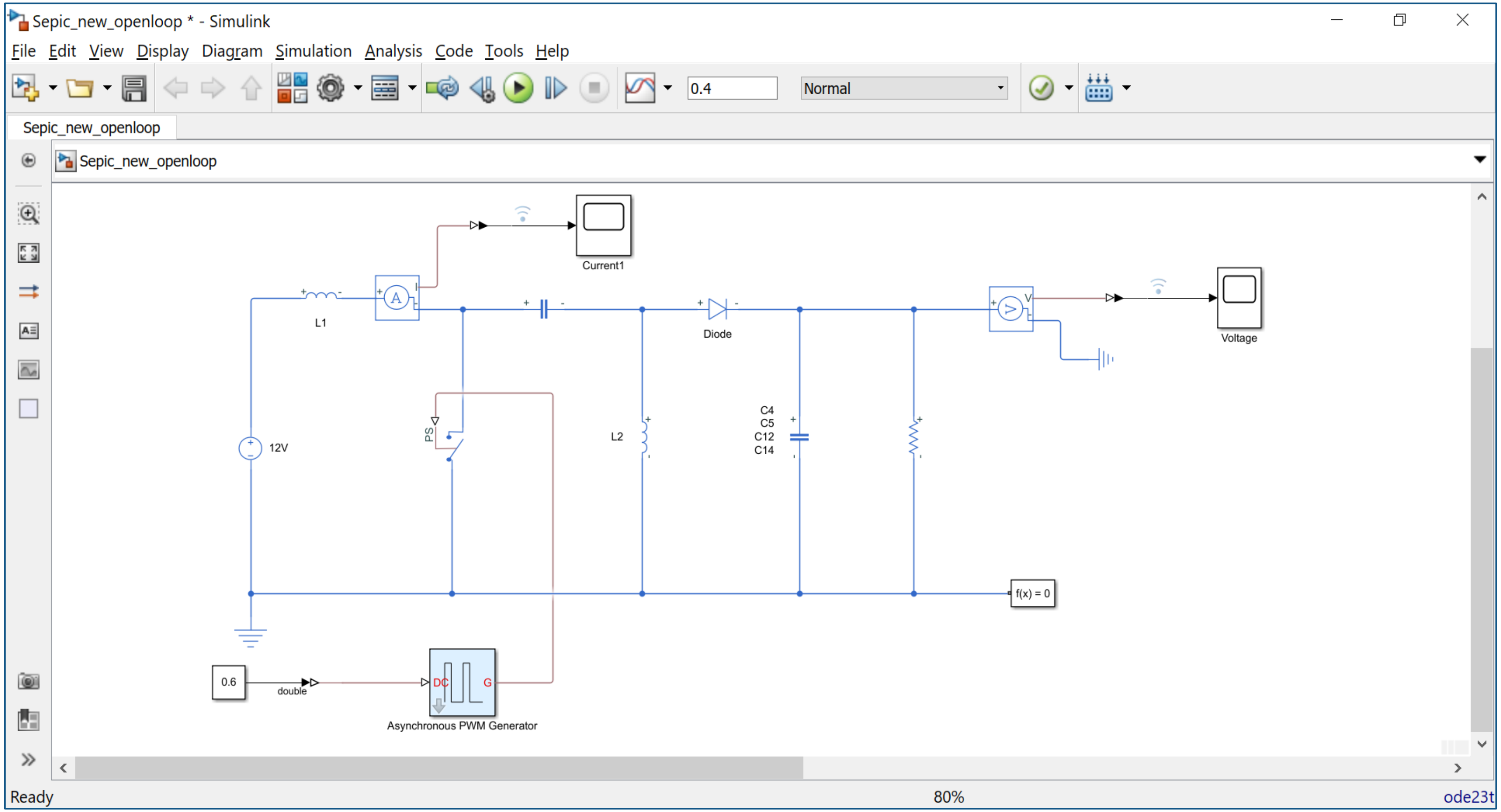
- Determine non linear switching and the thermal behavior of the converter

- Design control algorithm based on time/frequency domain specification

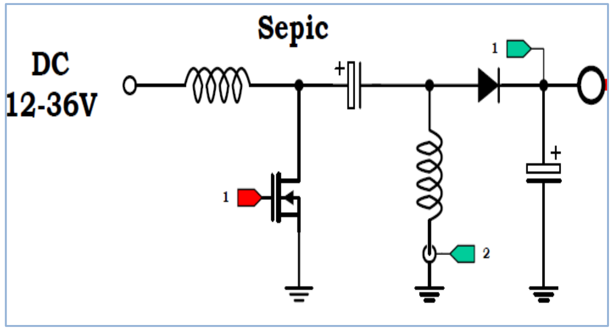
- Implement power electronic controls on an embedded processor

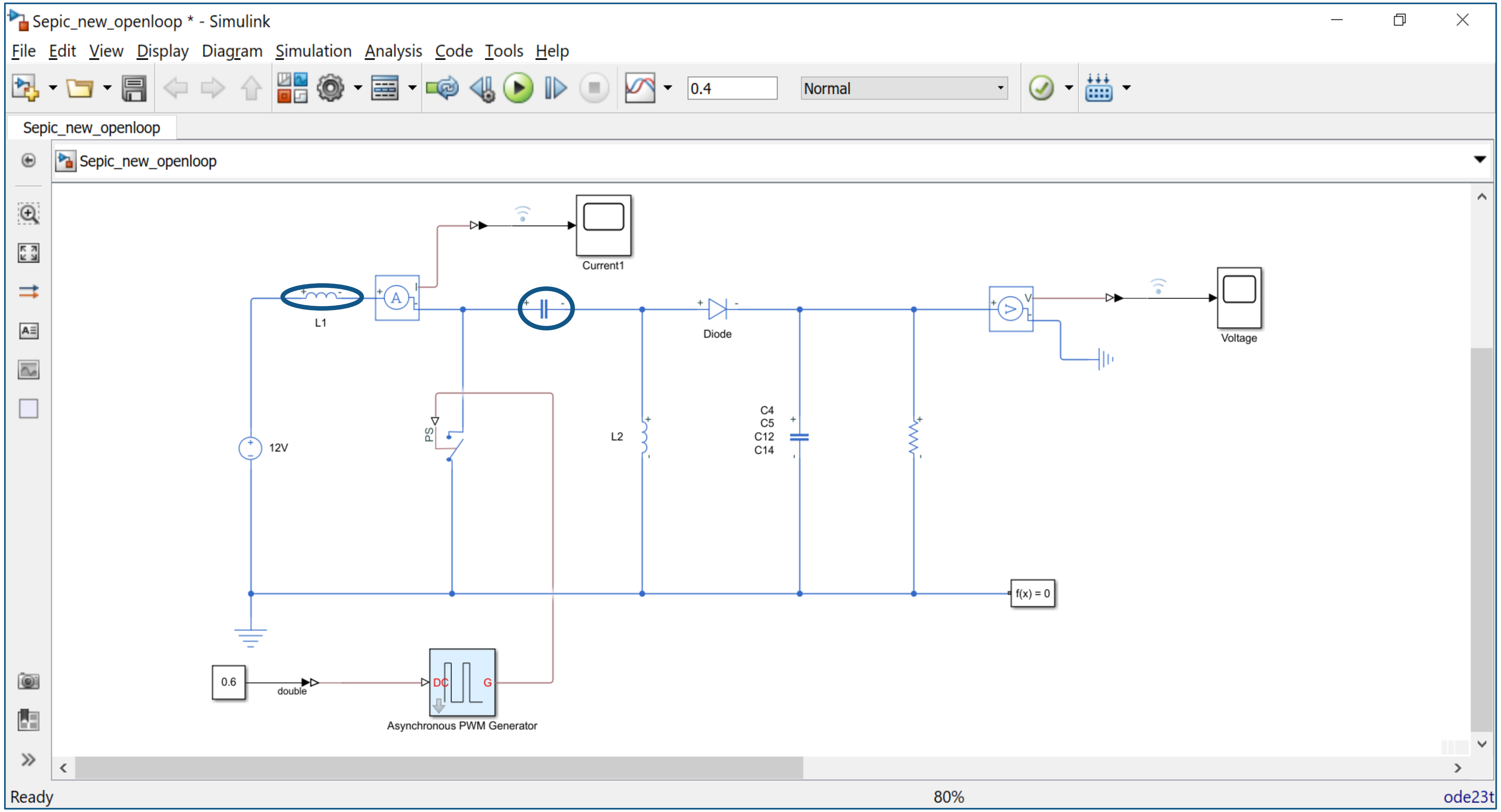
Simscape model for DC-DC Sepic Converter



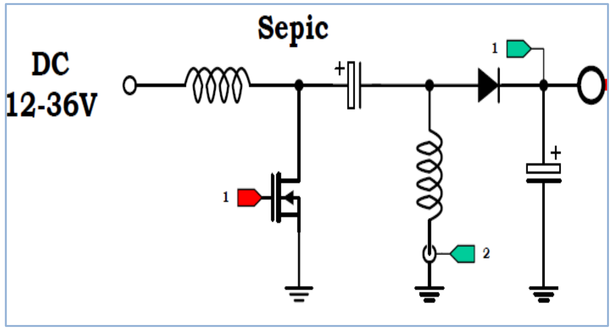


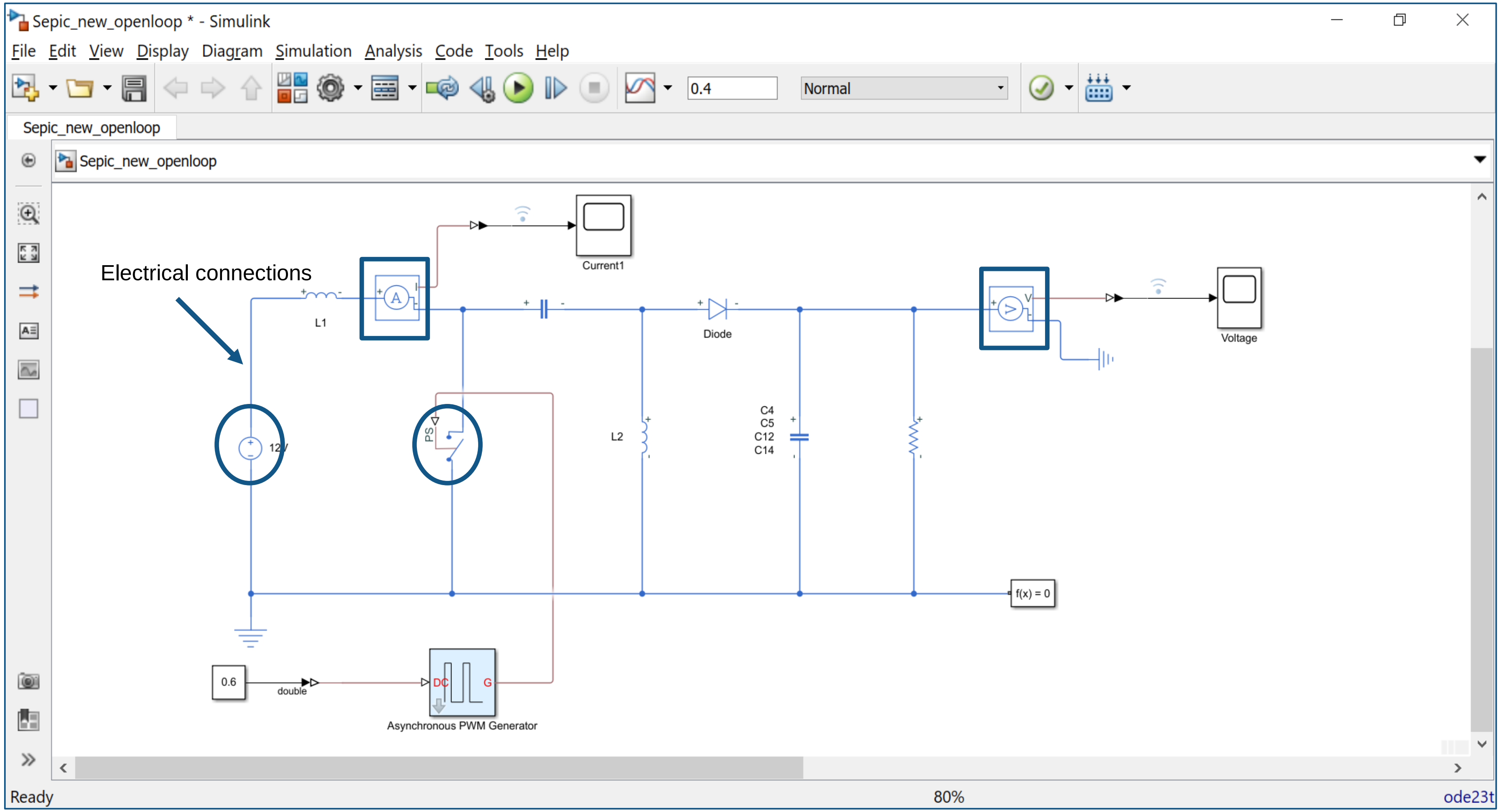
Simscape model for DC-DC Sepic Converter

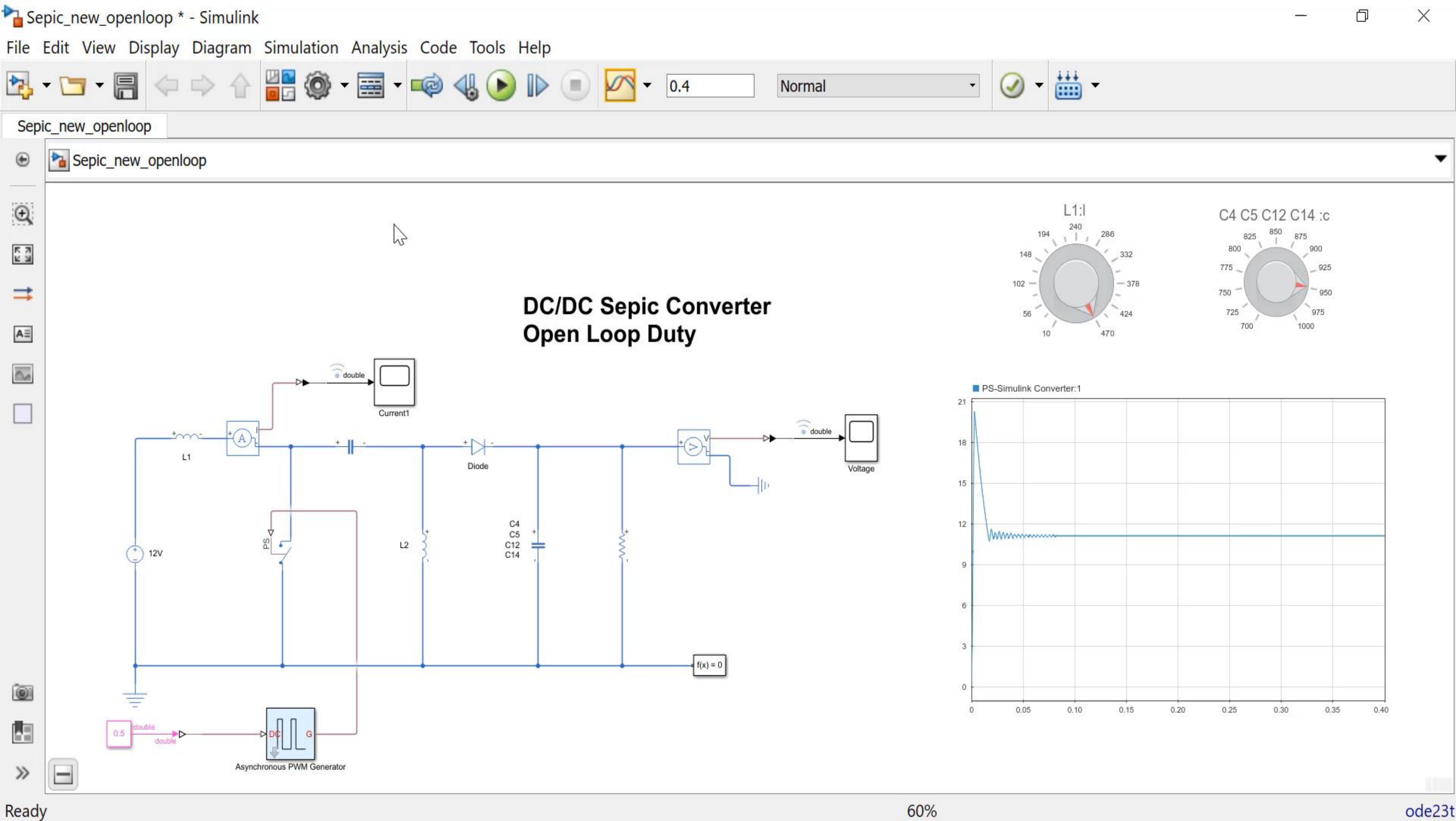


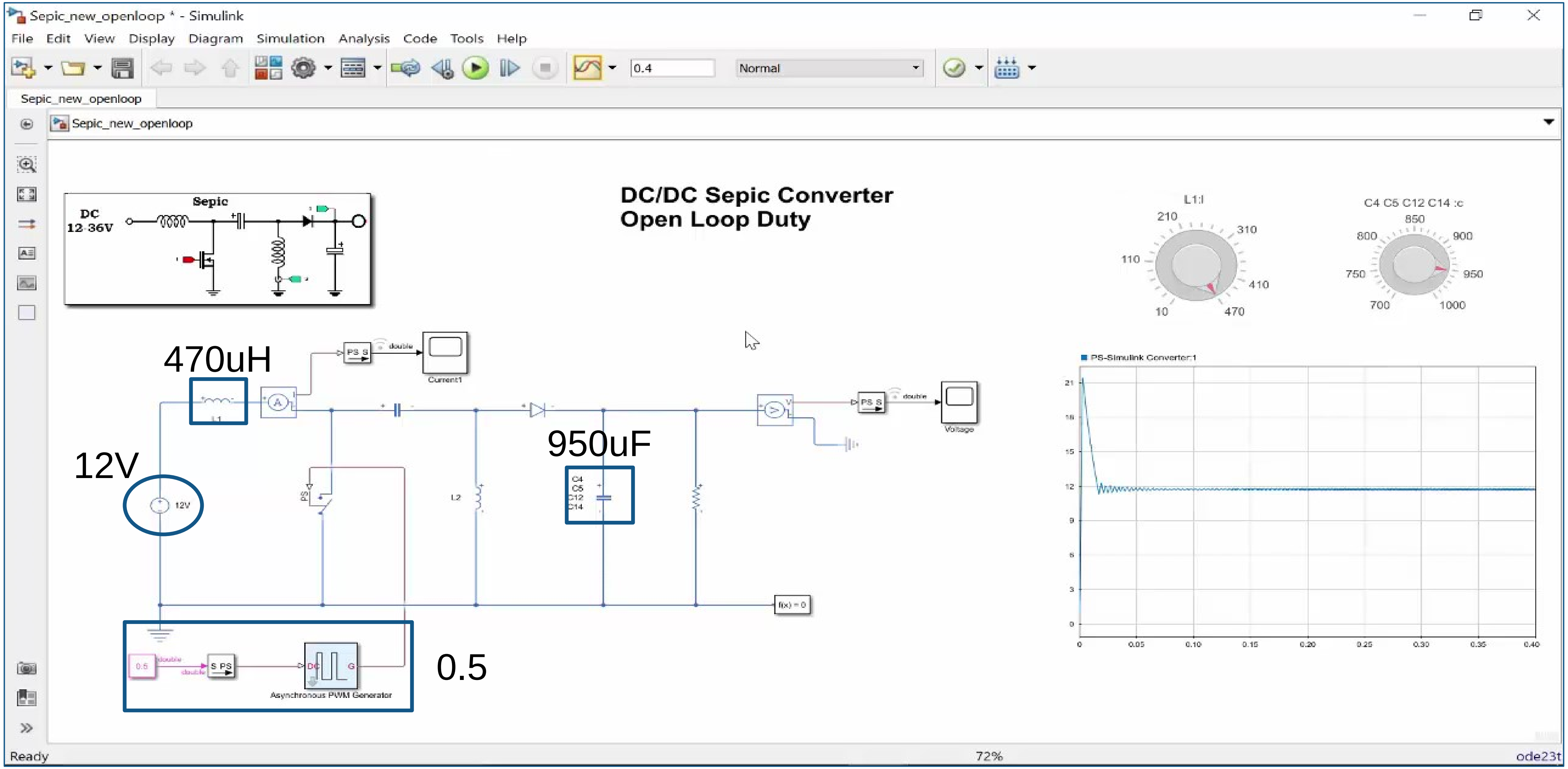


Simscape model for DC-DC Sepic Converter

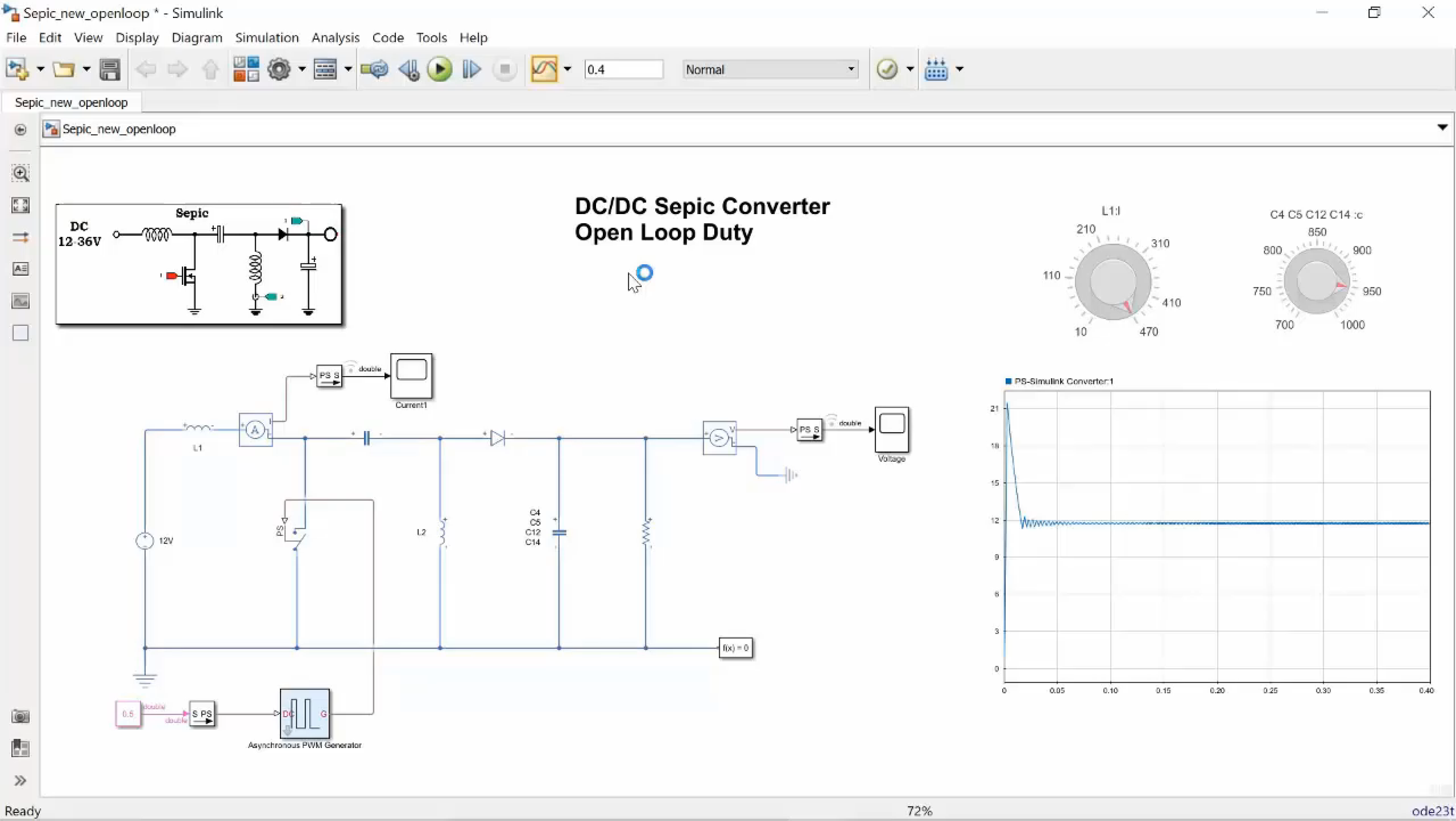





Sepic_new_openloop * - Simulink
File Edit View Display Diagram Simulation Analysis Code Tools Help
0.4
Normal
Sepic_new_openloop
Sepic_new_openloop
DC/DC Sepic Converter
Open Loop Duty
L1:l
C4 C5 C12 C14 :c
double
Current1
L1
Diode
double
Voltage
PS-Simulink Converter:1
C4
C5
C12
C14
L2
12V
f(x) = 0
0.5
double
double
DC
G
Asynchronous PWM Generator
Ready
60%
ode23t

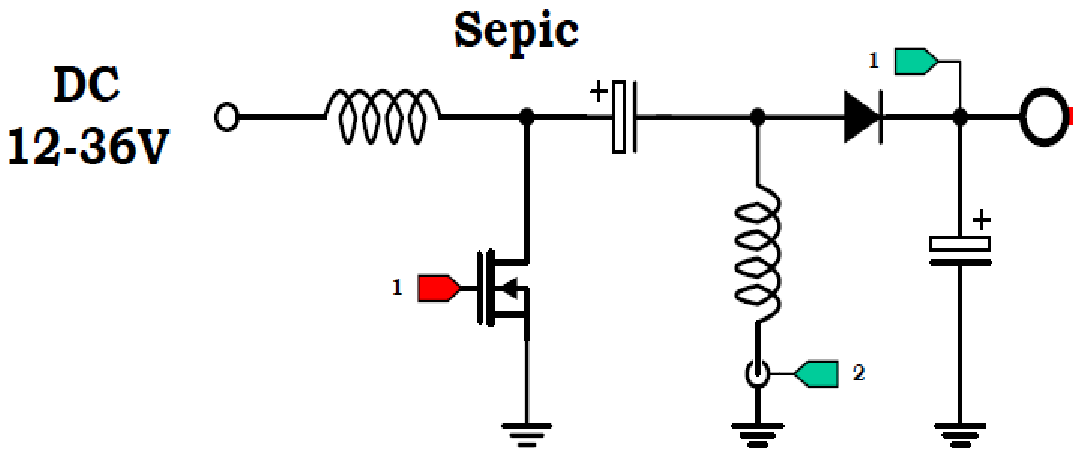


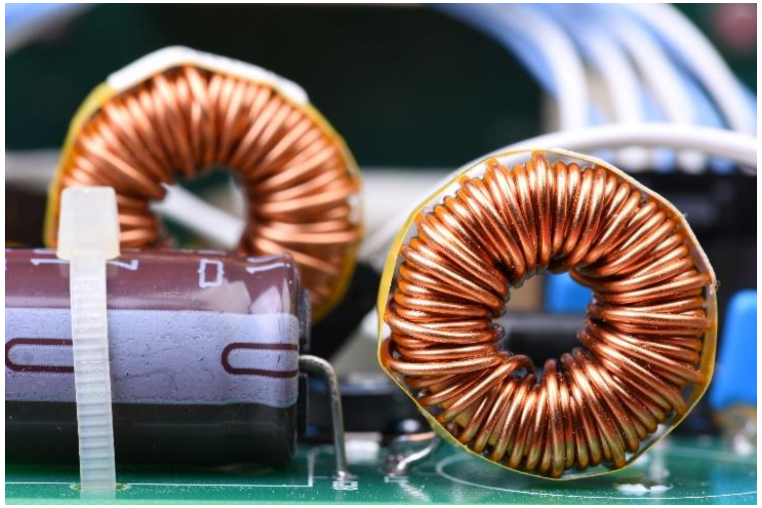
Sepic_new_openloop * - Simulink
File Edit View Display Diagram Simulation Analysis Code Tools Help
0.4
Normal
Sepic_new_openloop
DC/DC Sepic Converter
Open Loop Duty
DC 12-36V
Sepic
L1:l
C4 C5 C12 C14 :c
470uH
12V
950uF
0.5
Current1
Voltage
Asynchronous PWM Generator
f(x) = 0
PS-Simulink Converter:1
Ready
72%
ode23t



Sepic_new_openloop * - Simulink
File Edit View Display Diagram Simulation Analysis Code Tools Help
0.4
Normal
Sepic_new_openloop
Sepic_new_openloop
Sepic
DC
12-36V
DC/DC Sepic Converter
Open Loop Duty
L1:l
210
310
110
410
10
470
C4 C5 C12 C14 :c
850
800
900
750
950
700
1000
PS S
double
Current1
L1
PS S
double
Voltage
12V
L2
C4
C5
C12
C14
f(x) = 0
0.5
double
double
S PS
DC
G
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

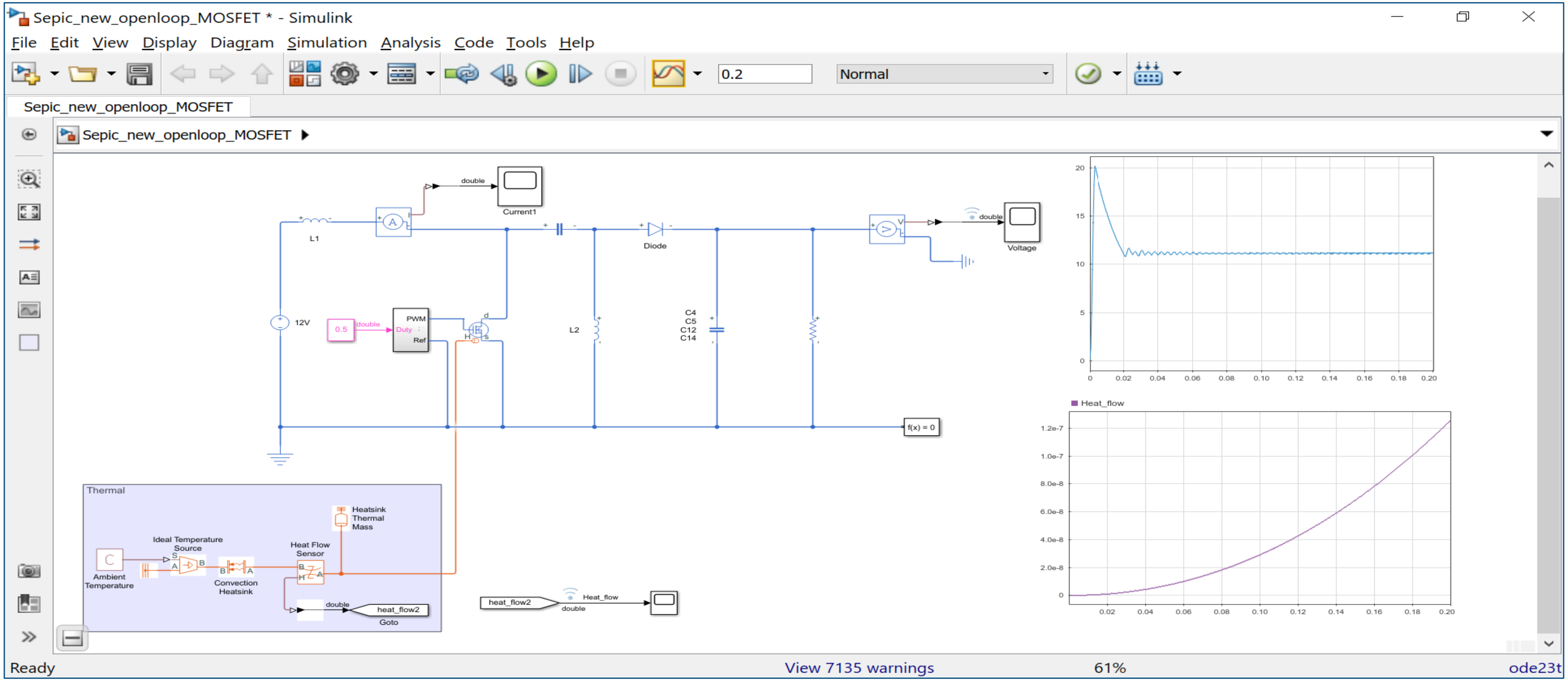
- Size inductor, capacitor and understand the behaviour in continuous and discontinuous mode

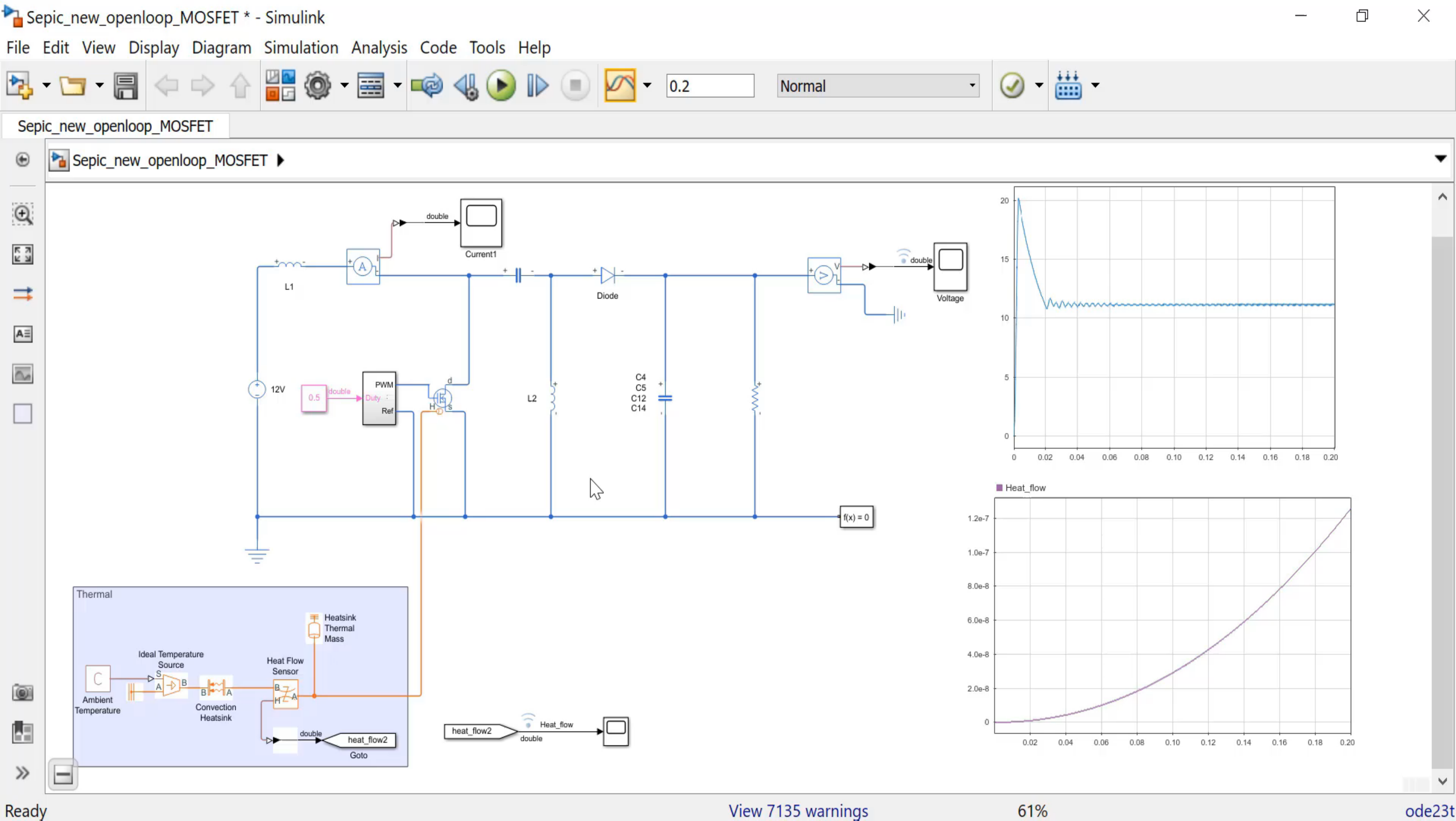
- **Determine non linear switching and the thermal behaviour of the converter**

- Design control algorithm based on time/frequency domain specification

- Implement power electronic controls on an embedded processor

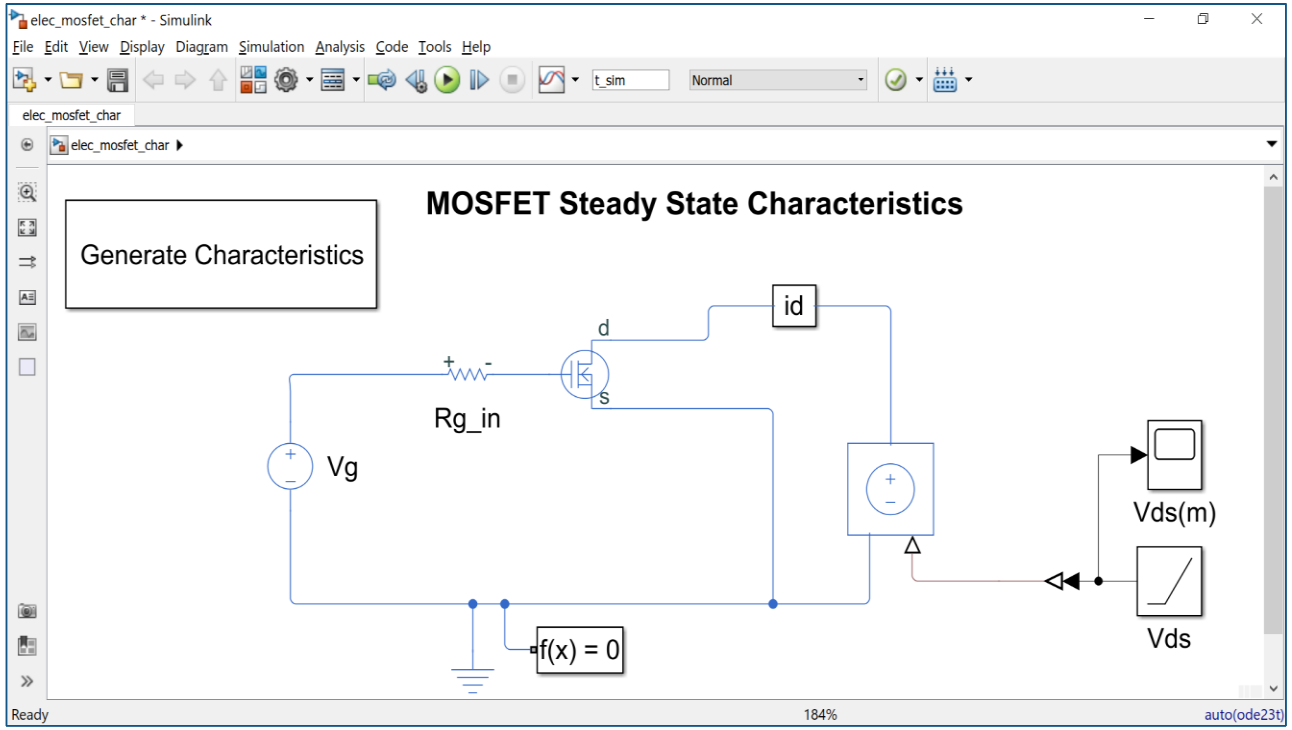
DC-DC Sepic converter with Non-Linear Switching Dynamics

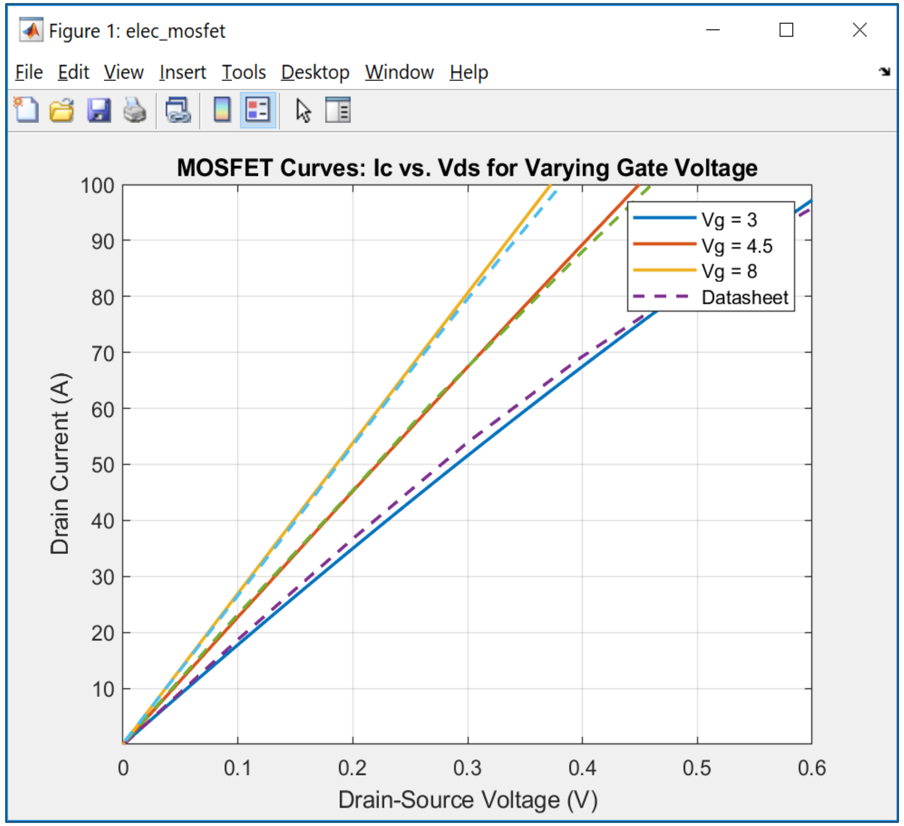




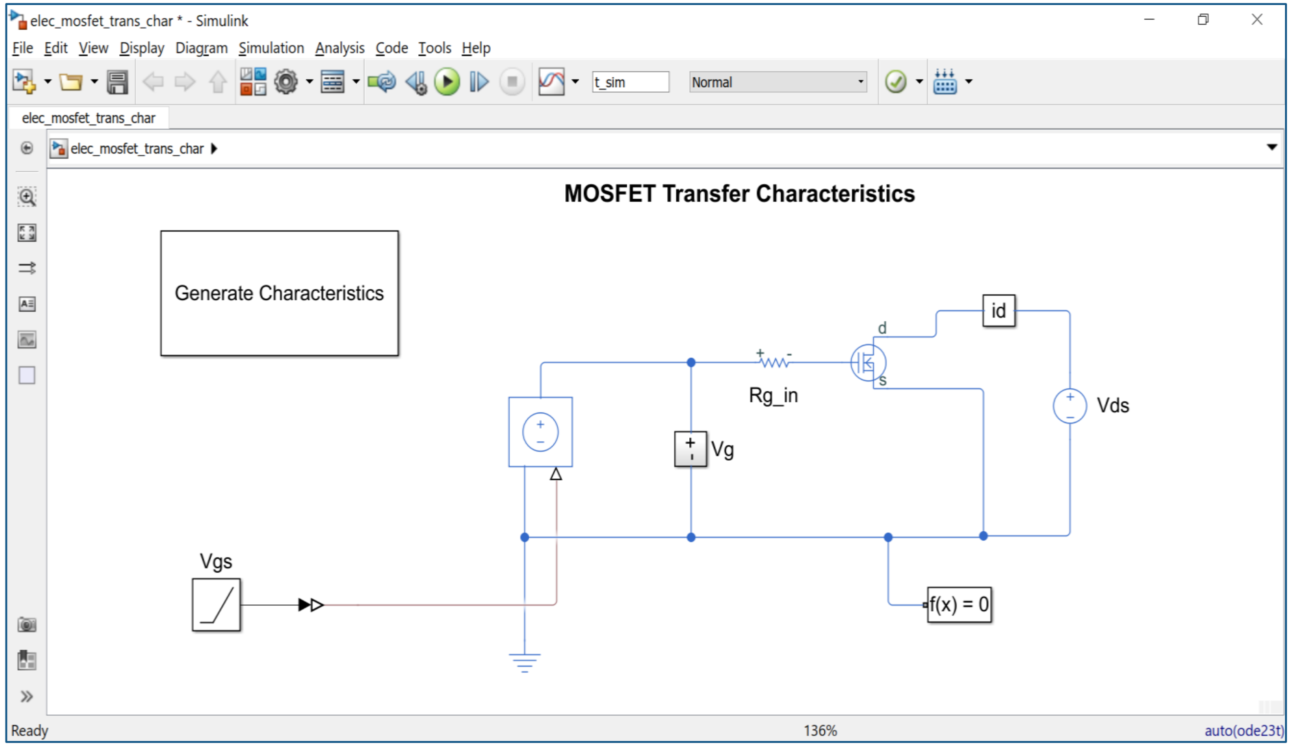
Sepic_new_openloop_MOSFET * - Simulink
File Edit View Display Diagram Simulation Analysis Code Tools Help
0.2
Normal
Sepic_new_openloop_MOSFET
Sepic_new_openloop_MOSFET
double
Current1
L1
Diode
double
Voltage
12V
0.5
double
PWM
Duty
Ref
L2
C4
C5
C12
C14
f(x) = 0
Thermal
Heatsink
Thermal
Mass
Ideal Temperature
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

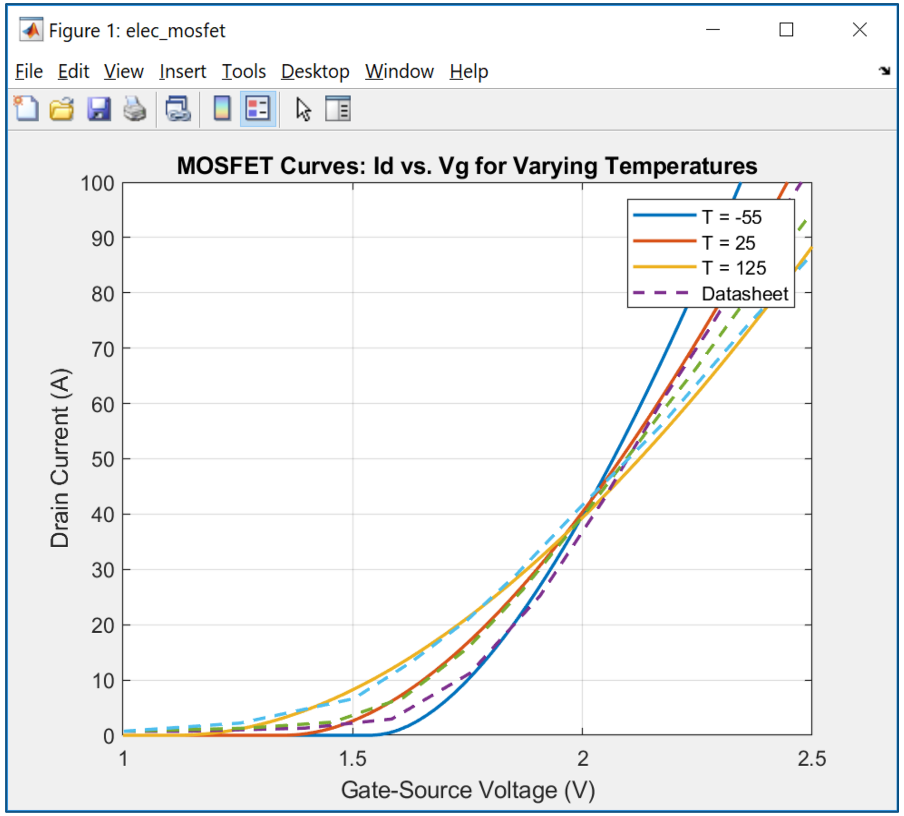
Comparison of N-Channel MOSFET Characteristics With Datasheet

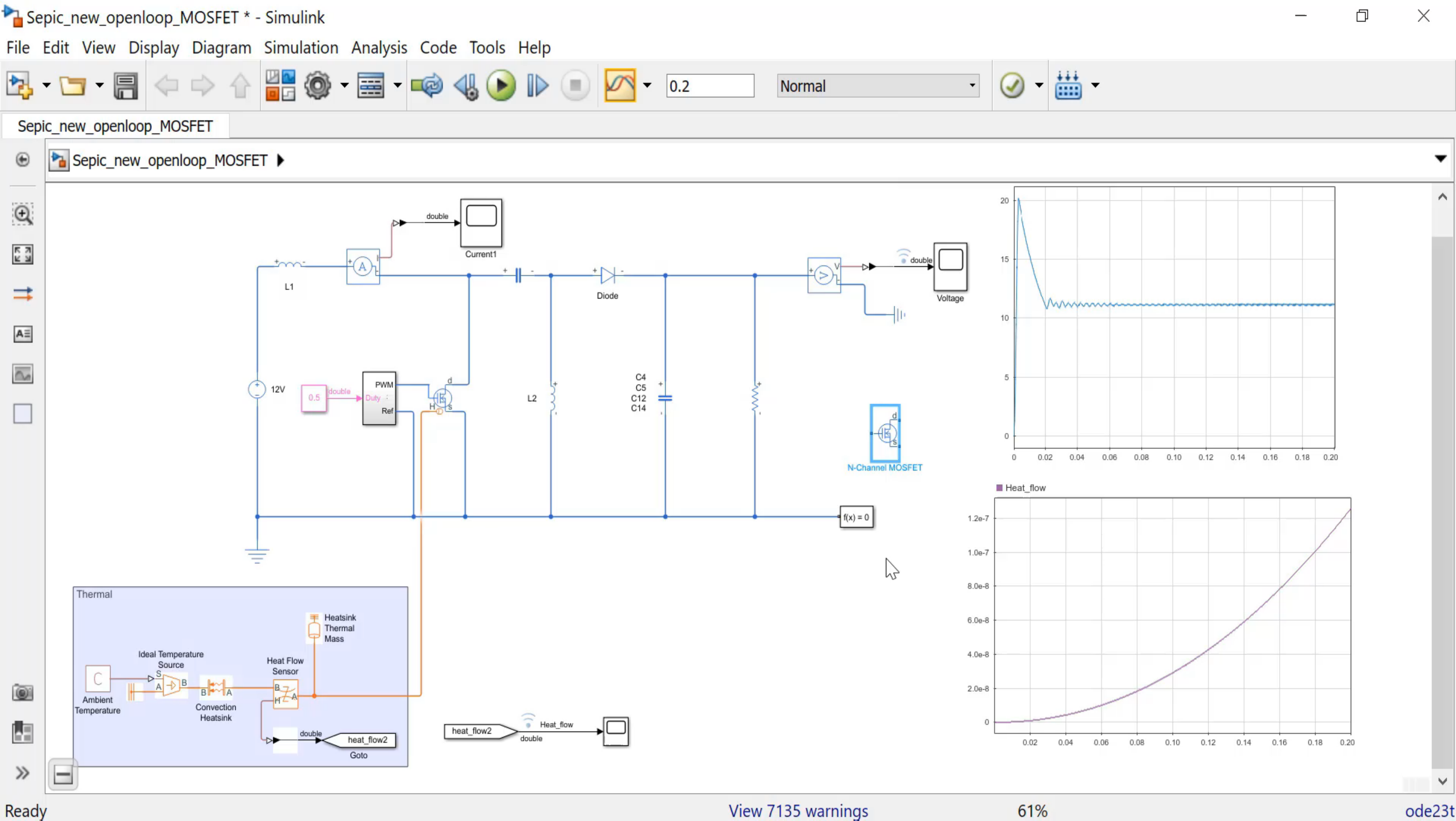




Comparison of N-Channel MOSFET Characteristics With Datasheet

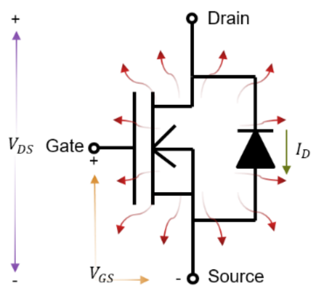




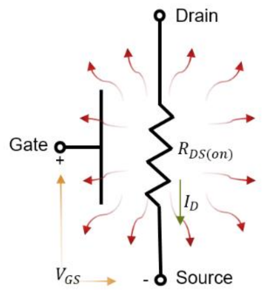


Sepic_new_openloop_MOSFET * - Simulink
File
Edit
View
Display
Diagram
Simulation
Analysis
Code
Tools
Help
0.2
Normal
Sepic_new_openloop_MOSFET
Sepic_new_openloop_MOSFET
double
Current1
L1
Diode
double
Voltage
12V
0.5
double
PWM
Duty
Ref
L2
C4
C5
C12
C14
N-Channel MOSFET
f(x) = 0
Heat_flow
Thermal
Heatsink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

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

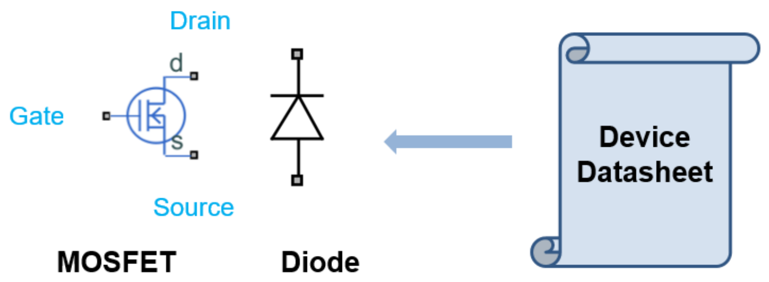


Switching loss



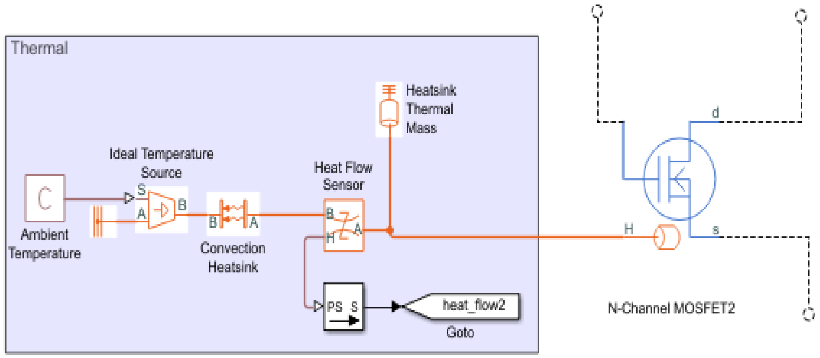
Conduction loss

Device Blocks



What we did

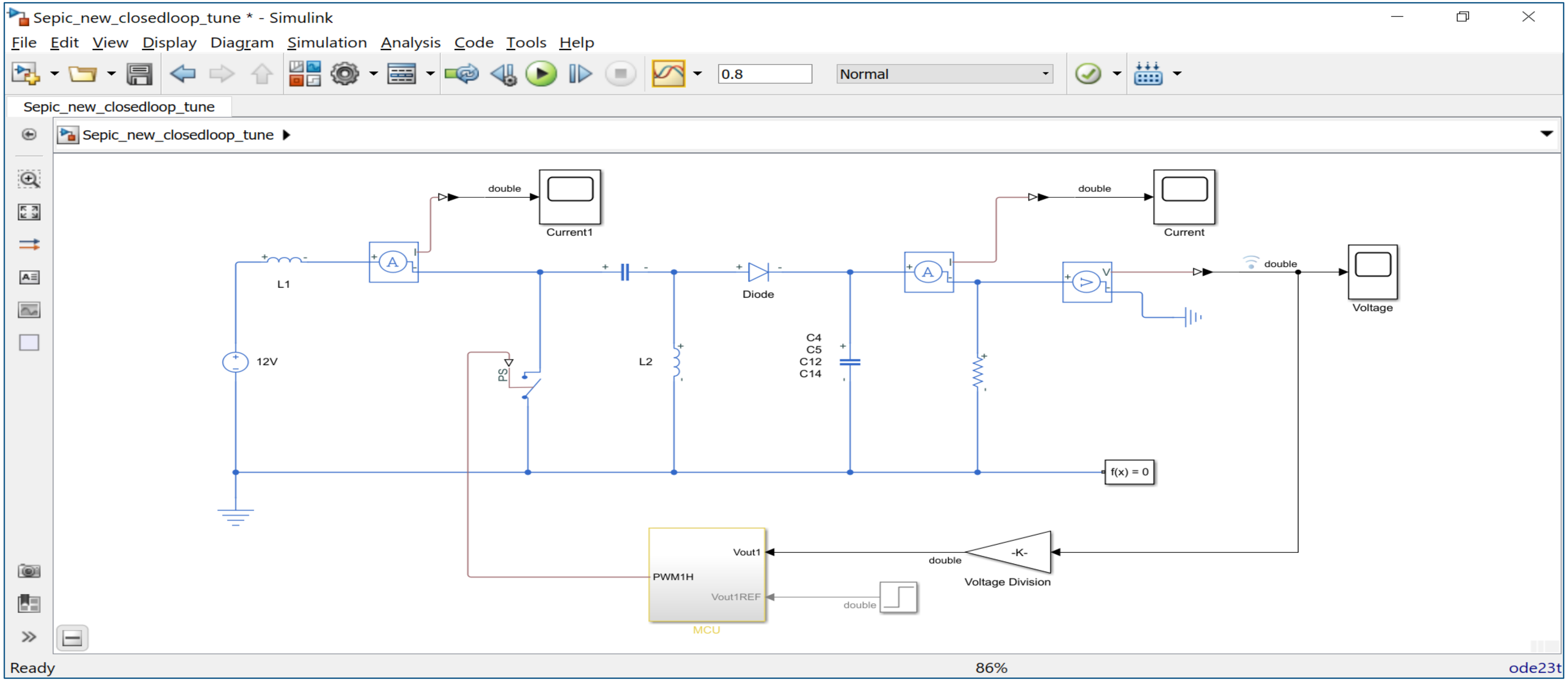
- Use semiconductor blocks from Simscape Electrical to model the non-linear switching behavior of SEPIC converter
- Leverage the multi-domain simulation capability of Simscape in understanding the thermal dynamics

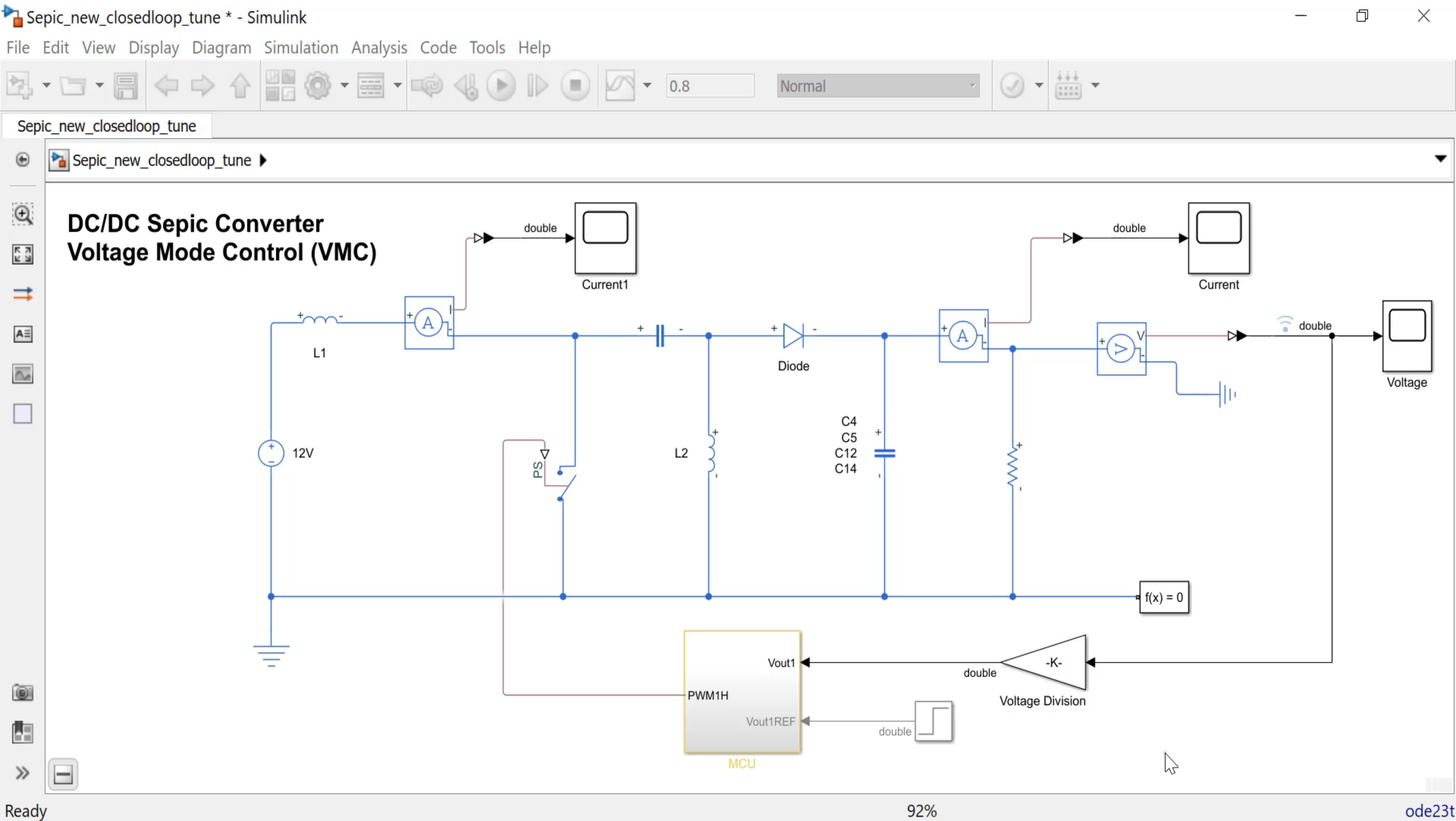


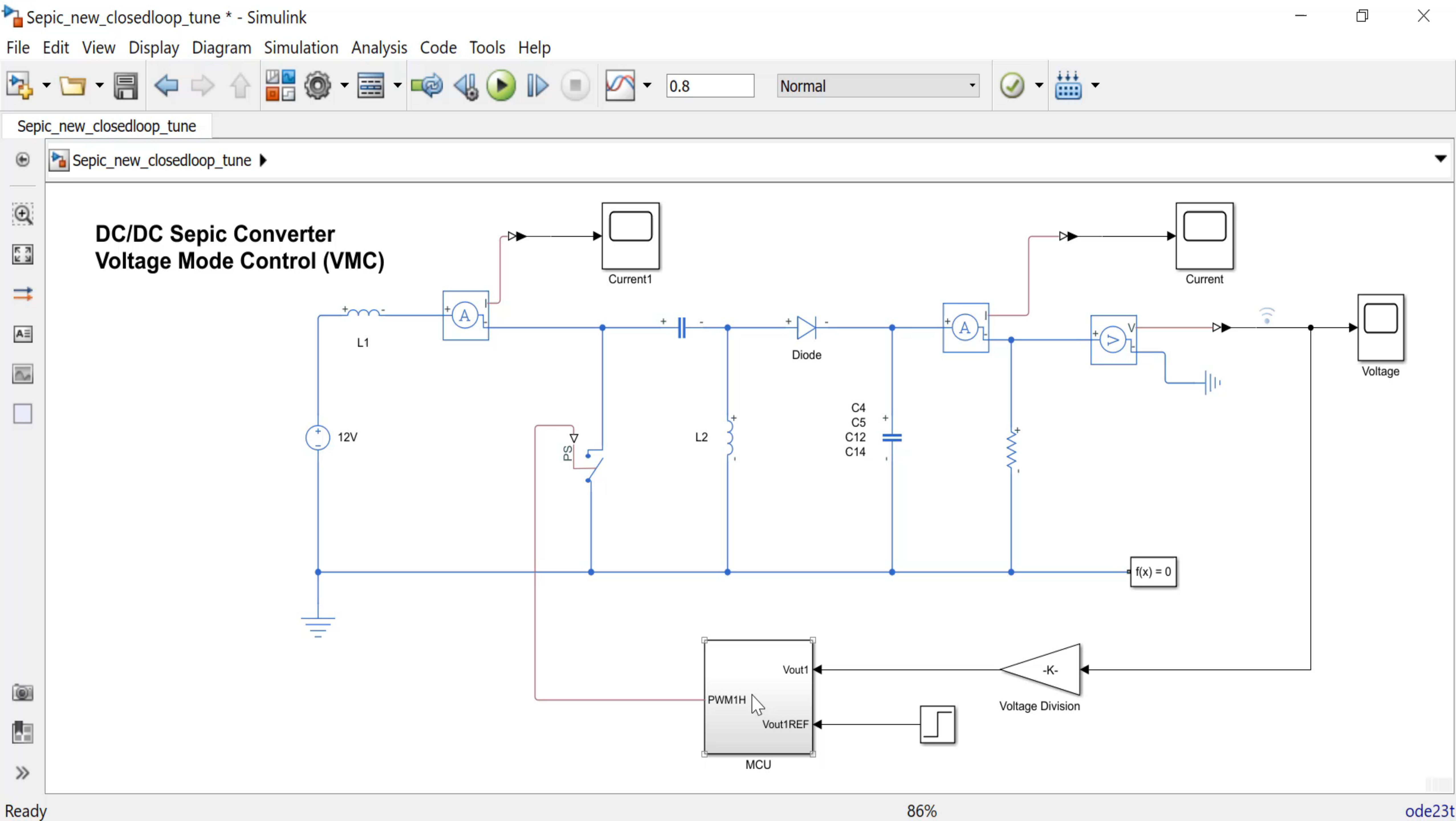
Power Converter Control Design Workflow Tasks

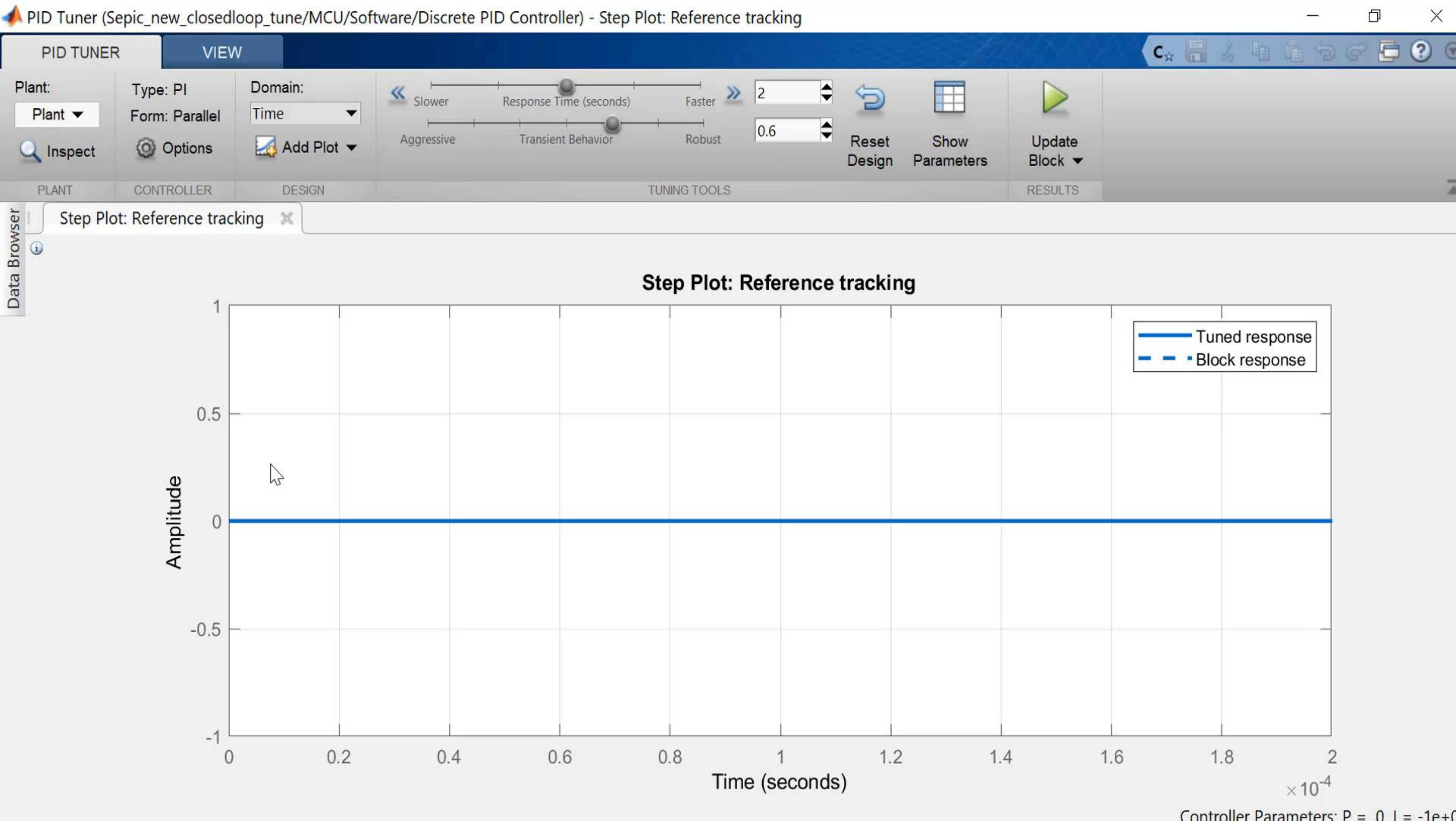
- Size inductor, capacitor and understand the behaviour in continuous and discontinuous mode
- Determine non linear switching and the thermal behavior of the converter
- **Design control algorithm based on time/frequency domain specification**
- Implement power electronic controls on an embedded processor

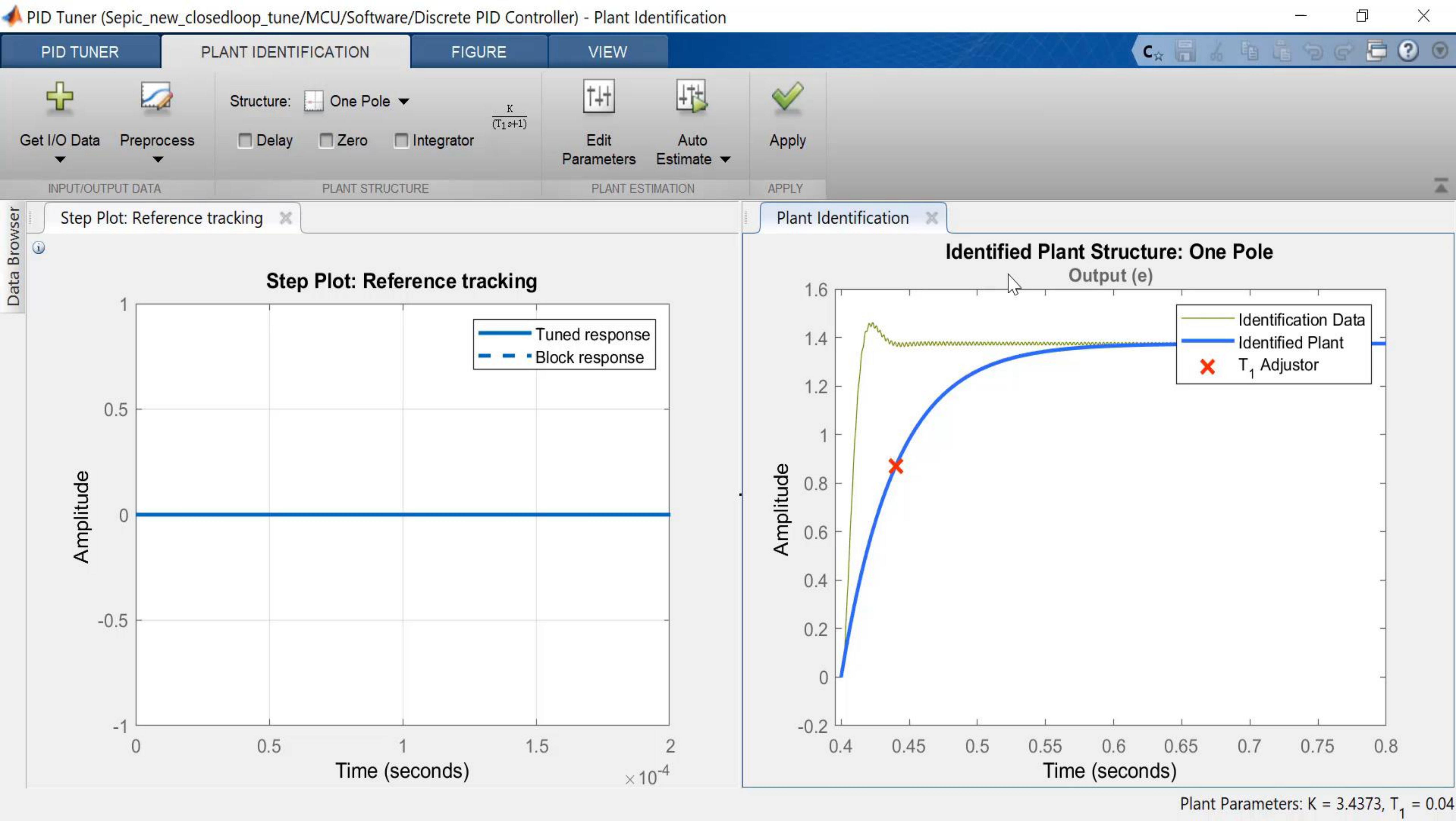
DC/DC Sepic Converter Voltage Mode Control (VMC)



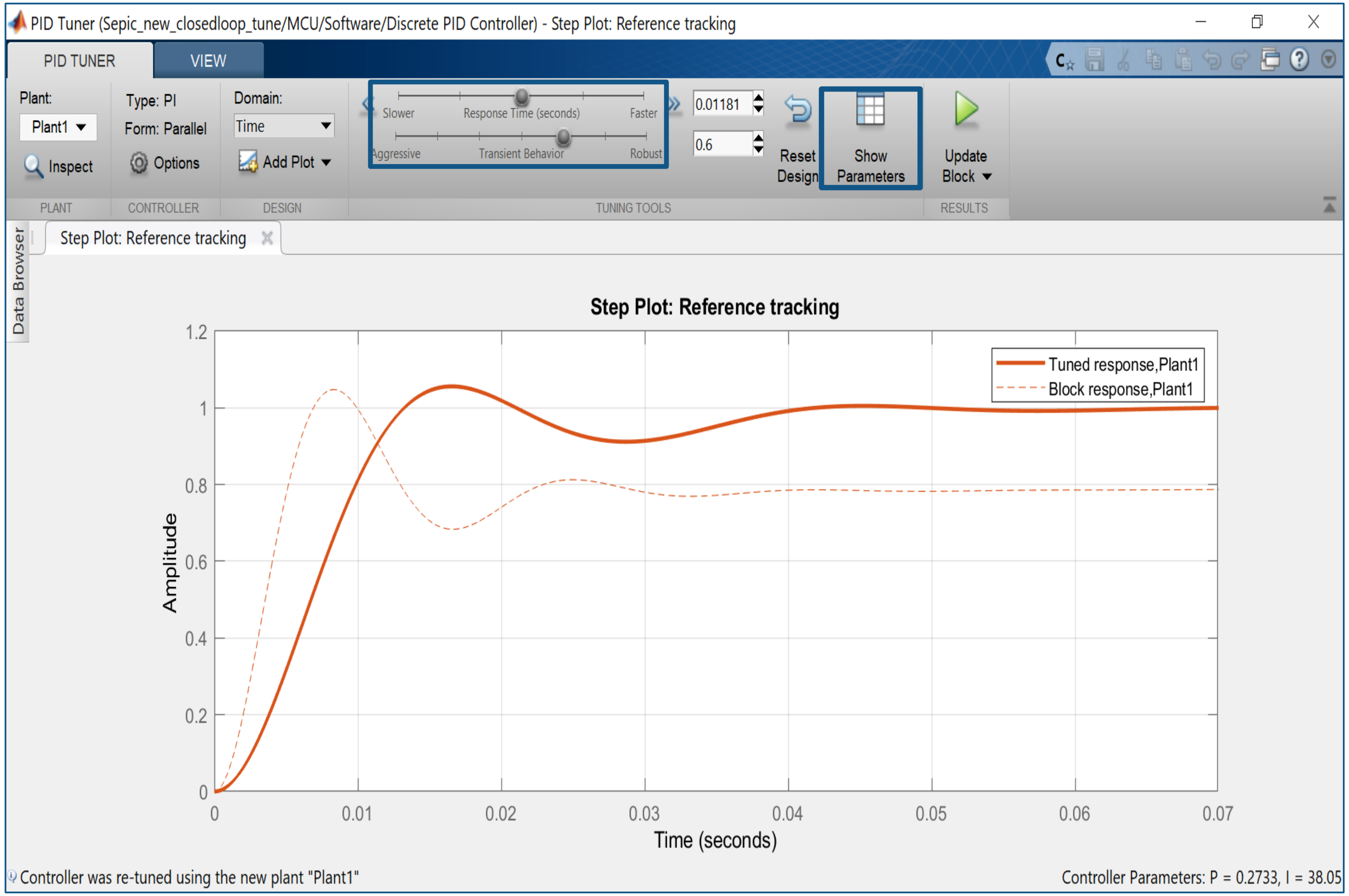

Sepic_new_closedloop_tune * - Simulink
File Edit View Display Diagram Simulation Analysis Code Tools Help
0.8
Normal
Sepic_new_closedloop_tune
Sepic_new_closedloop_tune
DC/DC Sepic Converter
Voltage Mode Control (VMC)
double
Current1
double
Current
double
Voltage
L1
Diode
12V
PS
L2
C4
C5
C12
C14
f(x) = 0
Vout1
PWM1H
Vout1REF
MCU
double
-K-
Voltage Division
double
Ready
92%
ode23t


Sepic_new_closedloop_tune * - Simulink
File Edit View Display Diagram Simulation Analysis Code Tools Help
0.8
Normal
Sepic_new_closedloop_tune
Sepic_new_closedloop_tune
DC/DC Sepic Converter
Voltage Mode Control (VMC)
Current1
Current
L1
Diode
Voltage
12V
PS
L2
C4
C5
C12
C14
f(x) = 0
Vout1
PWM1H
Vout1REF
MCU
-K-
Voltage Division
Ready
86%
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)
×10^-4
Controller Parameters: P = 0, I = -1e+


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 / (T1 s+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
Time (seconds)
×10^-4
Plant Identification
Identified Plant Structure: One Pole
Output (e)
Identification Data
Identified Plant
T1 Adjustor
Amplitude
Time (seconds)
Plant Parameters: K = 3.4373, T1 = 0.04

Controlling PID parameters

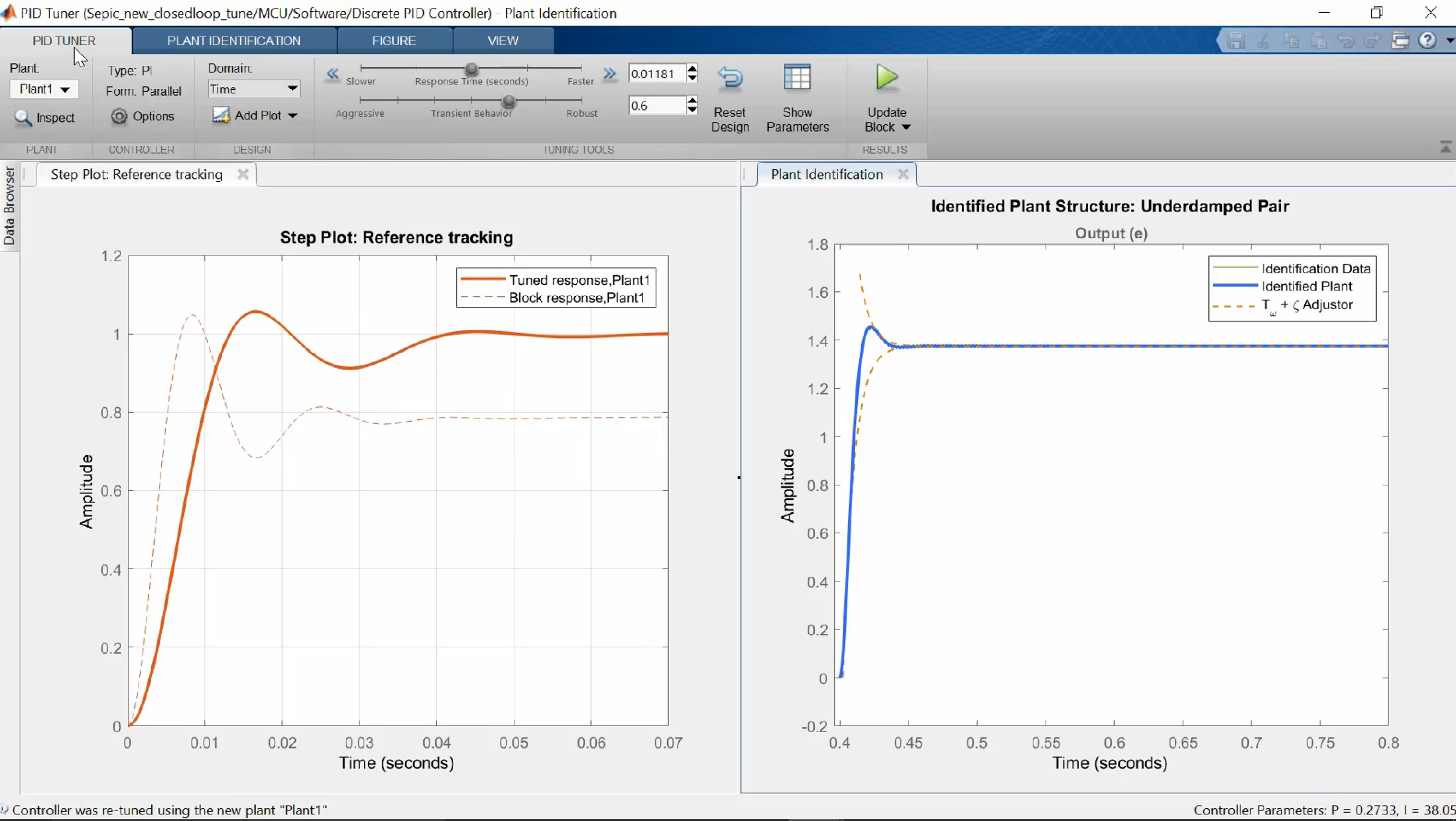


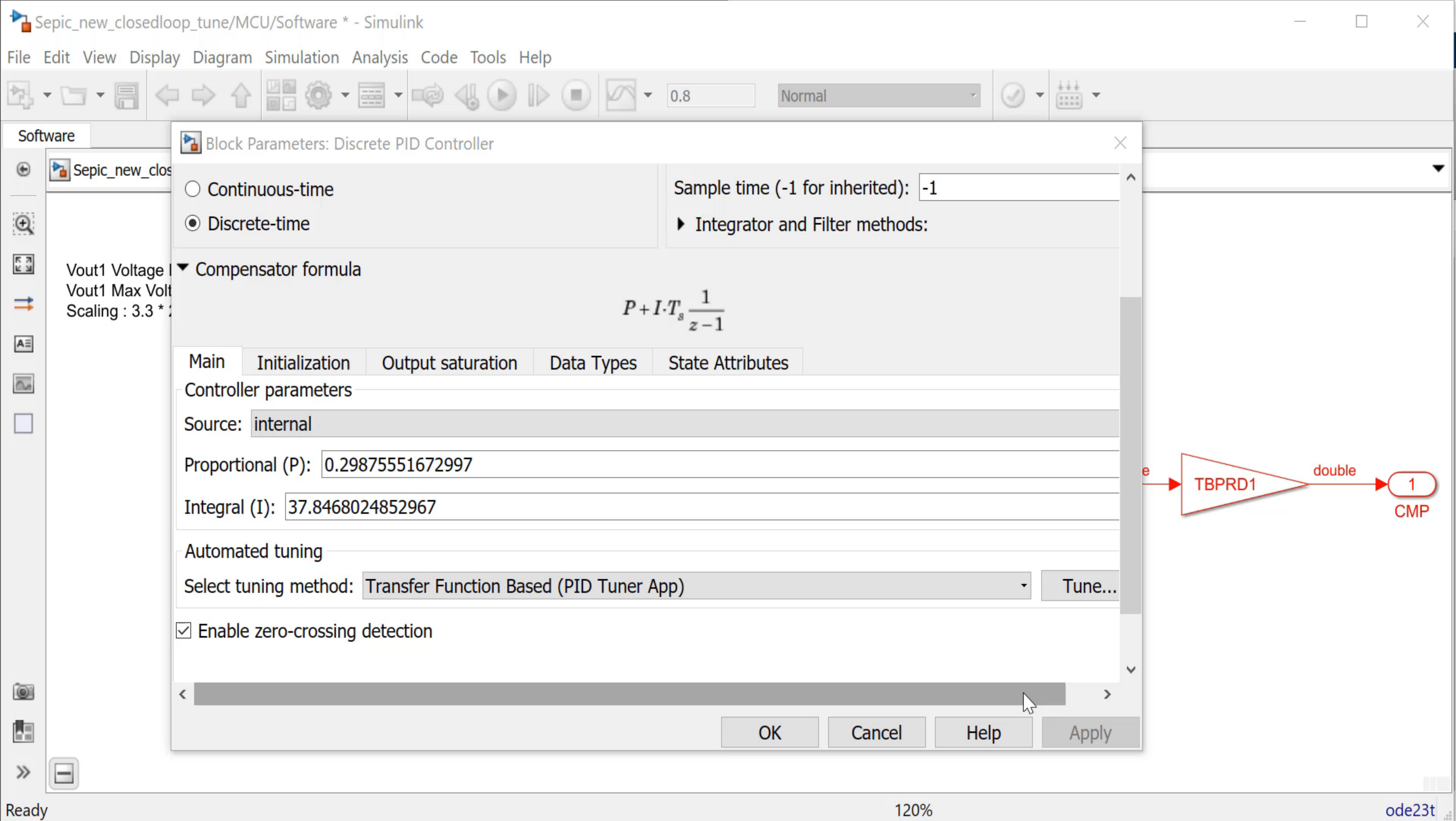
Controller Parameters

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

Performance and Robustness

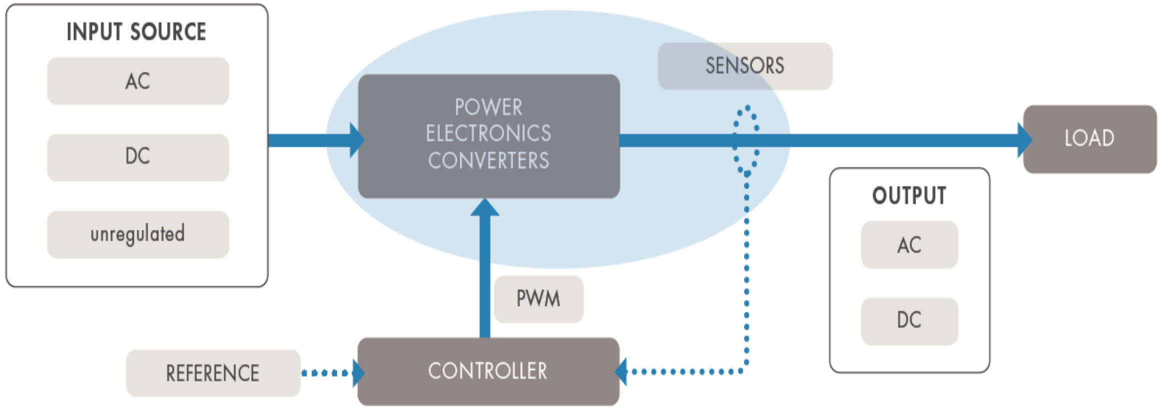
	Tuned	Block
Rise time	0.00864 seconds	0.00342 seconds
Settling time	0.0382 seconds	0.0351 seconds
Overshoot	5.6 %	32.9 %
Peak	1.06	1.05
Gain margin	147 dB @ 2.68e+05 ra...	361 dB @ 3.14e+05 r...
Phase margin	60 deg @ 169 rad/s	45.7 deg @ 349 rad/s
Closed-loop stability	Stable	Stable

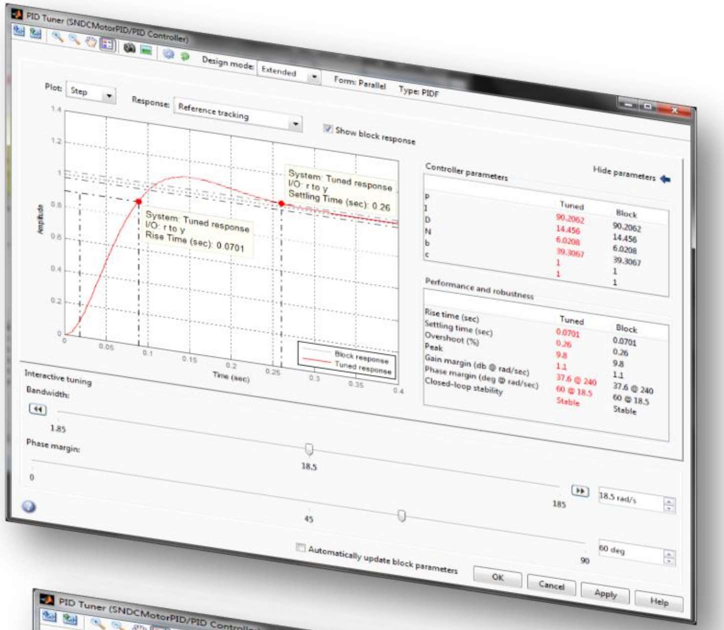

PID Tuner (Sepic_new_closedloop_tune/MCU/Software/Discrete PID Controller) - Plant Identification
PID TUNER
PLANT IDENTIFICATION
FIGURE
VIEW
Plant:
Plant1
Inspect
Type: PI
Form: Parallel
Options
Domain:
Time
Add Plot
Slower
Response Time (seconds)
Faster
0.01181
Aggressive
Transient Behavior
Robust
0.6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

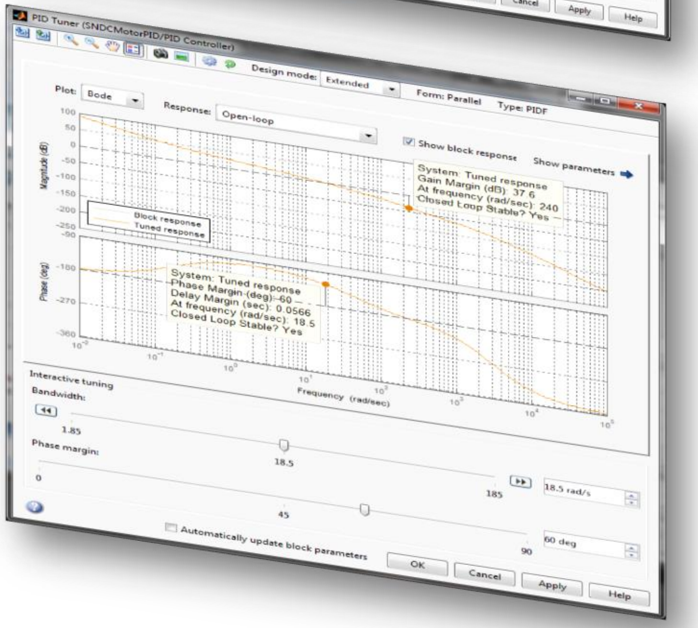


Sepic_new_closedloop_tune/MCU/Software * - Simulink
File Edit View Display Diagram Simulation Analysis Code Tools Help
0.8
Normal
Software
Sepic_new_clos
Vout1 Voltage
Vout1 Max Volt
Scaling : 3.3 *
Block Parameters: Discrete PID Controller
Continuous-time
Discrete-time
Sample time (-1 for inherited): -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







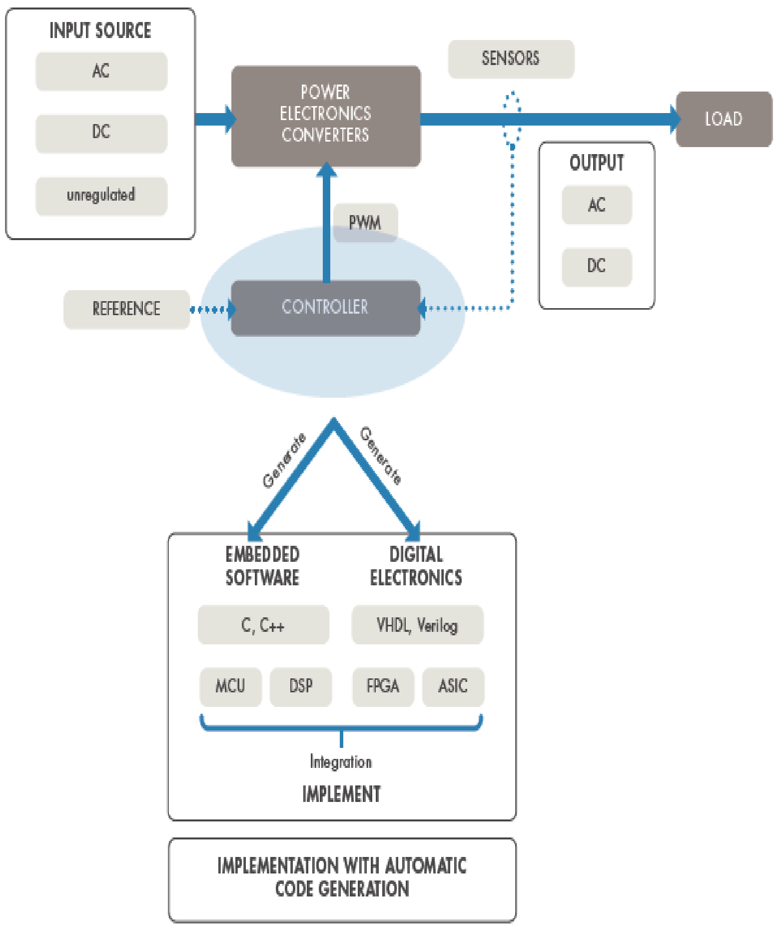
What we did

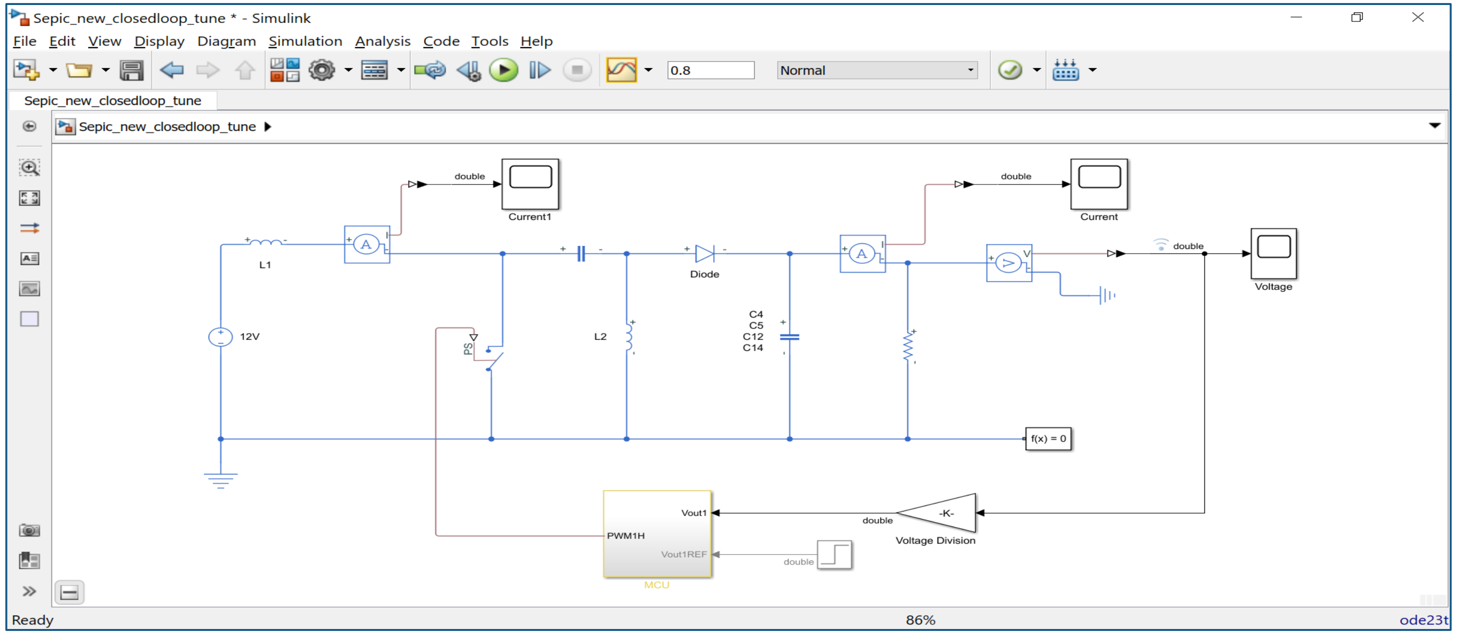
- Identify plant model from input output simulation data
- Use auto tuning algorithms to tune the control gains

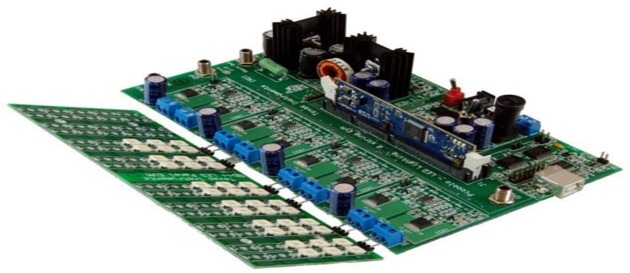
Power Converter Control Design Workflow Tasks

- Size inductor, capacitor and understand the behaviour in continuous and discontinuous mode
- Determine non linear switching and the thermal behavior of the converter
- Design control algorithm based on time/frequency domain specification
- **Implement power electronic controls on an embedded processor**

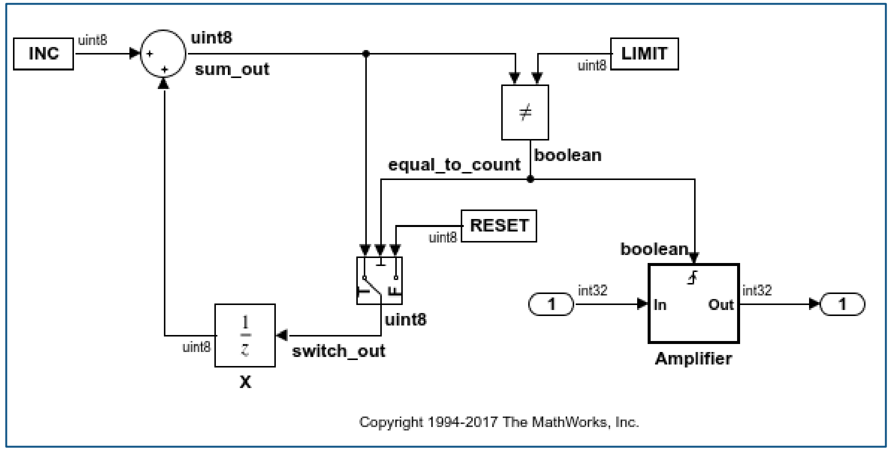
Implementing Control for Power Converters on TI DC-DC LED Developer Kit



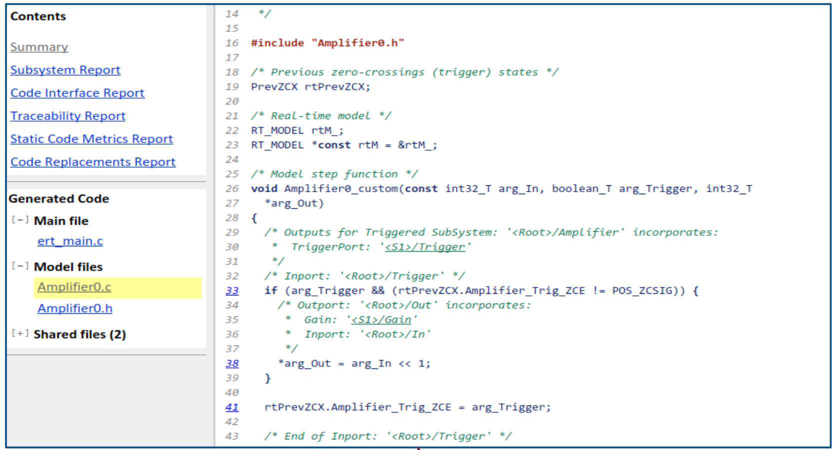




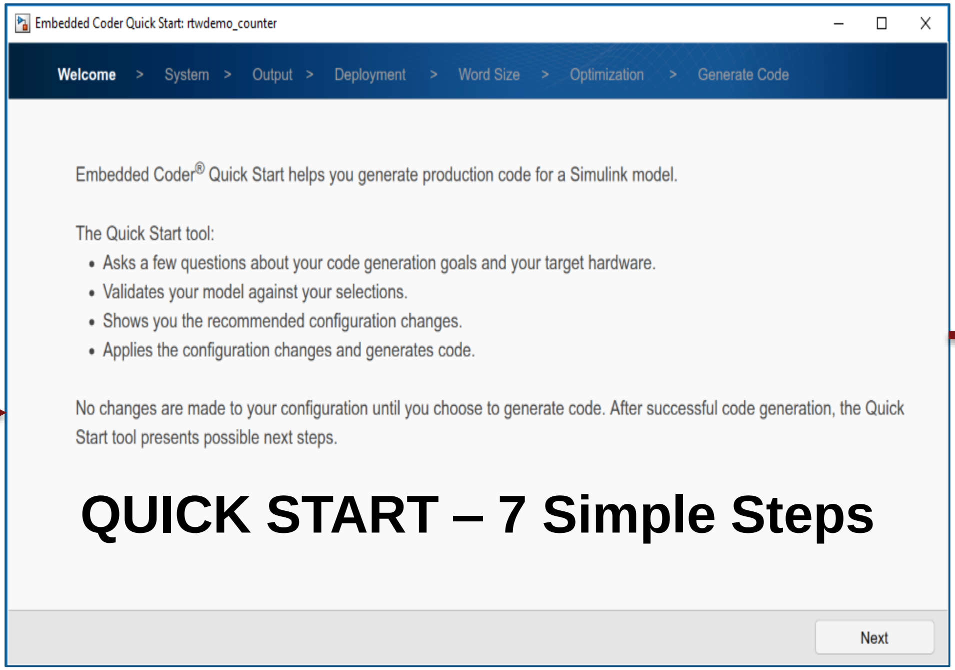
Fast Code Generation Using Embedded Coder Quick Start



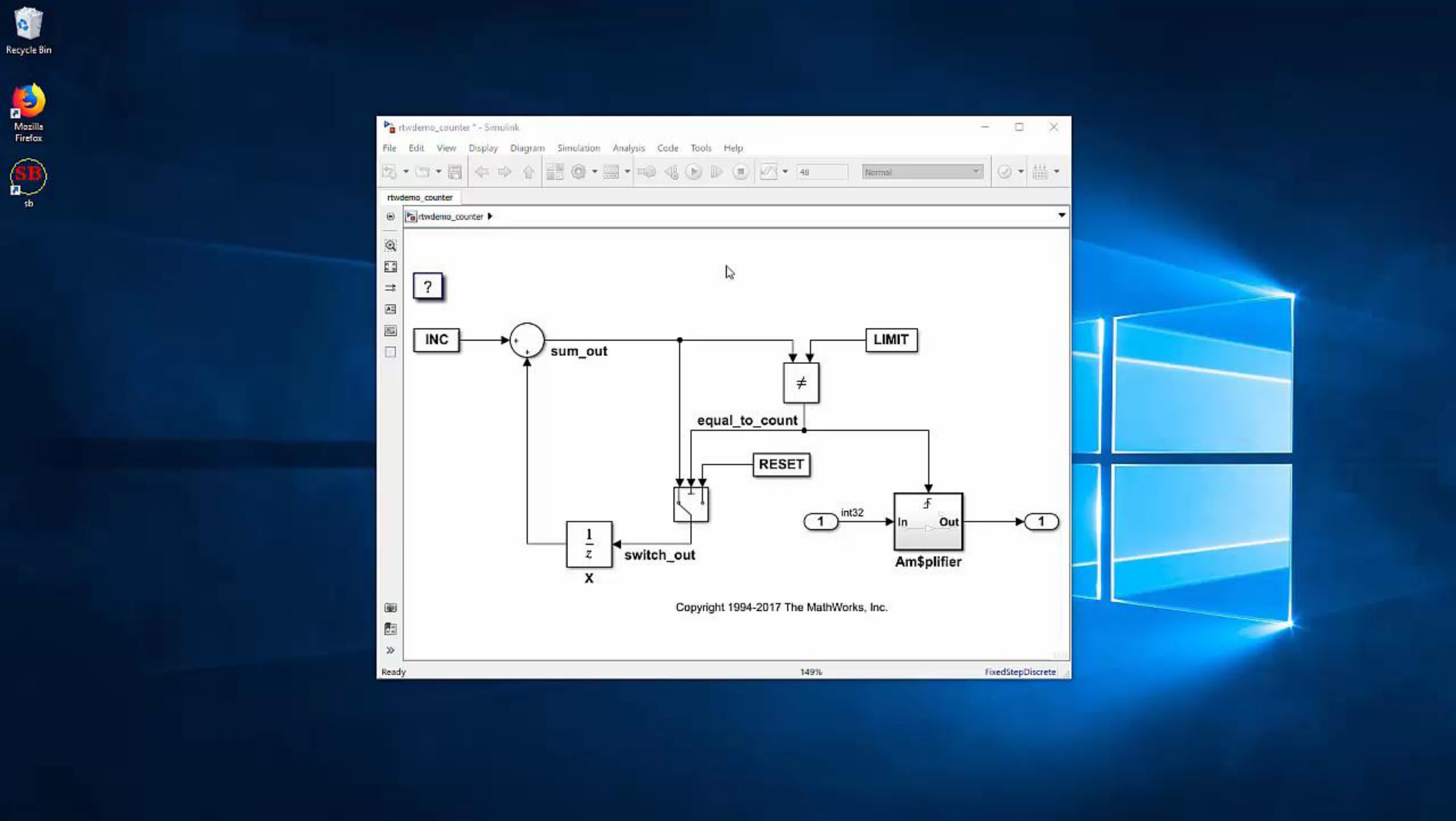
SIMULINK MODEL



GENERATED CODE



QUICK START – 7 Simple Steps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Code Generation Report

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Contents

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

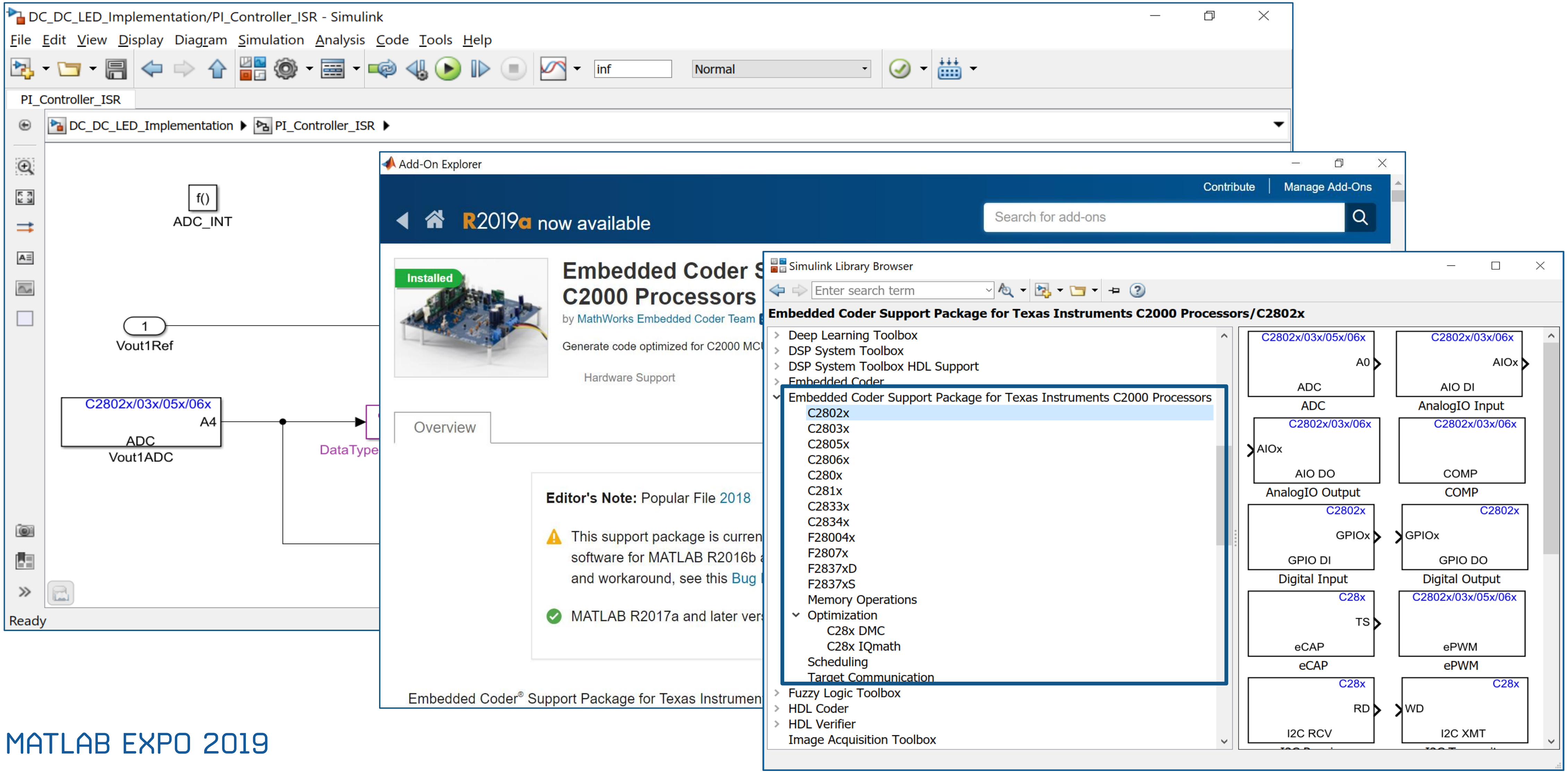
Author	vivekr
Last Modified By	vivekr
Model Version	1.252
Tasking Mode	MultiTasking

Configuration settings at time of code generation

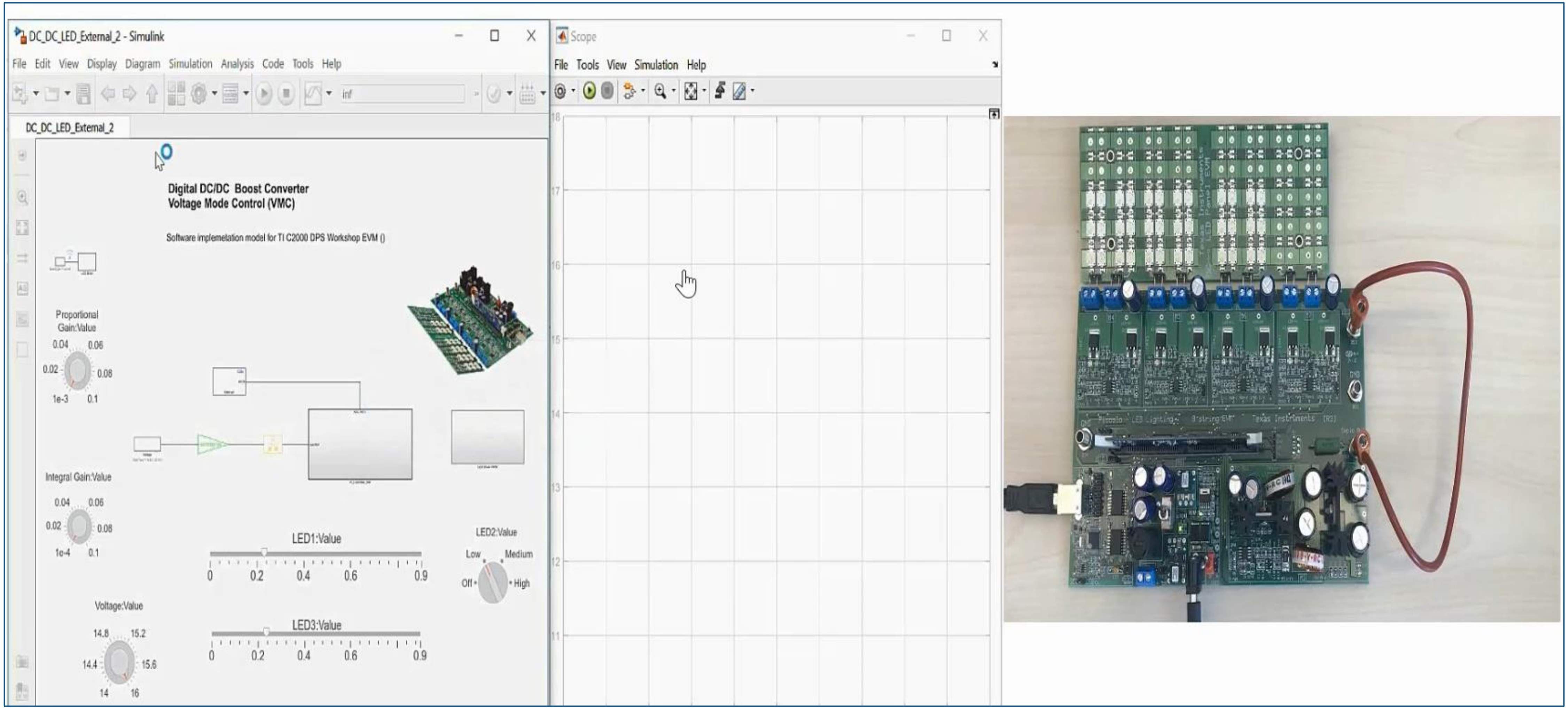
Code Information

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

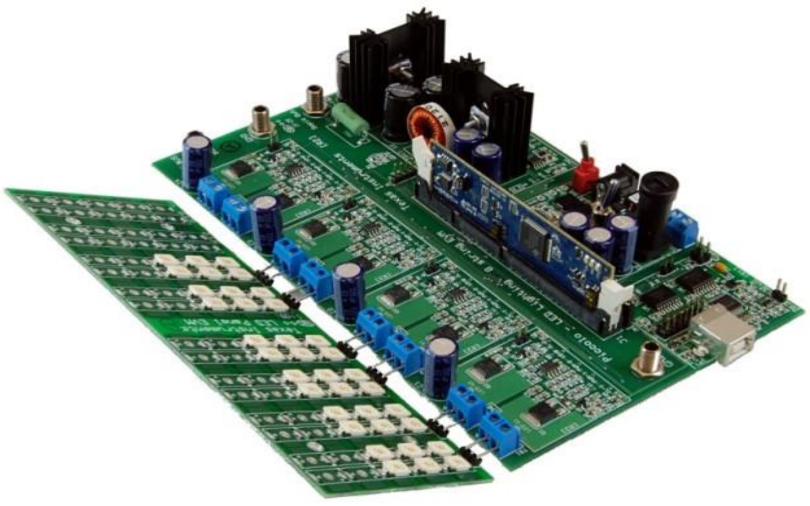
Control Algorithm deployment to TI controller and Parameter Tuning using External Mode

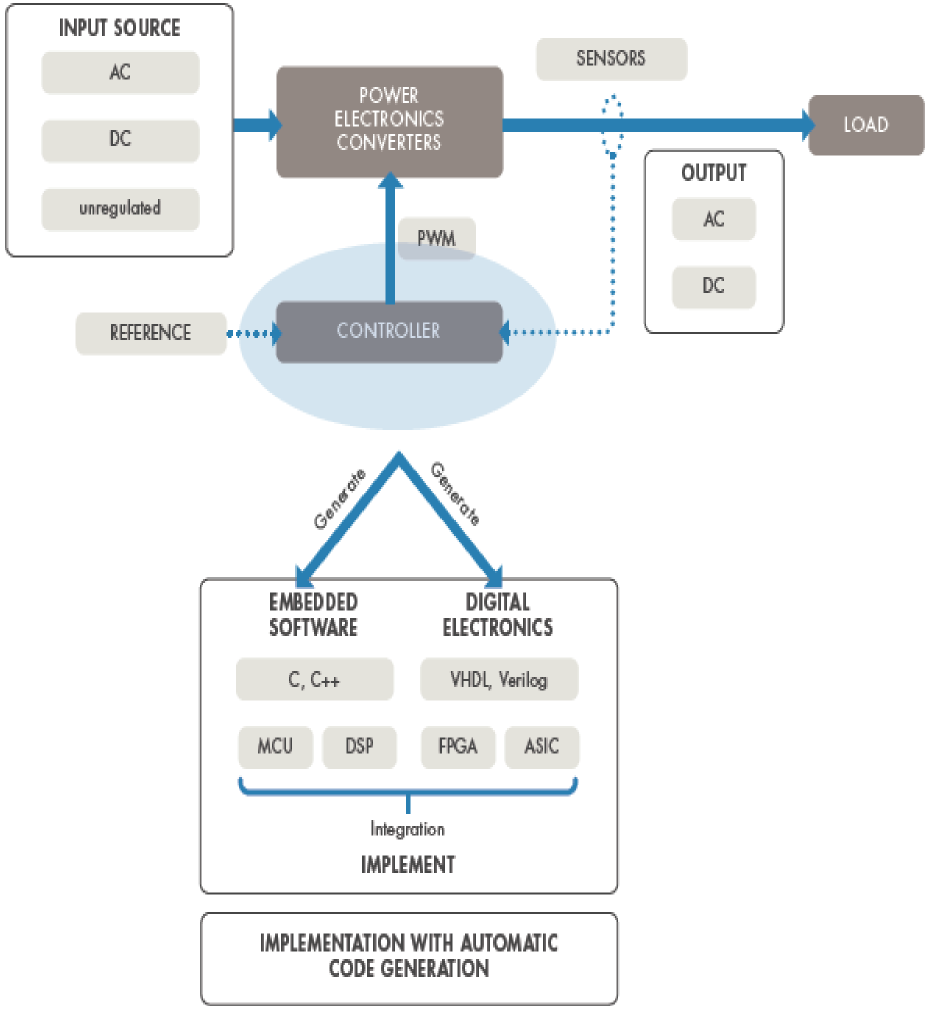


Implementation Of Power Electronics Control On Embedded Processor



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

How We Addressed The Challenges

- Understand the impact of the power source and load
- Testing for a complete range of operating and fault conditions
- Designing and implementing digital controls using *only* SPICE simulator tools
- Catching errors during software-hardware integration testing
- Compliance to industry standards
- Development Time

- **Size inductor, capacitor and understand the behaviour in continuous and discontinuous mode**
- **Determine non linear switching and the thermal behavior of the converter**
- **Design control algorithm based on time/frequency domain specification**
- **Implement power electronic controls on an embedded processor**

Call To Action

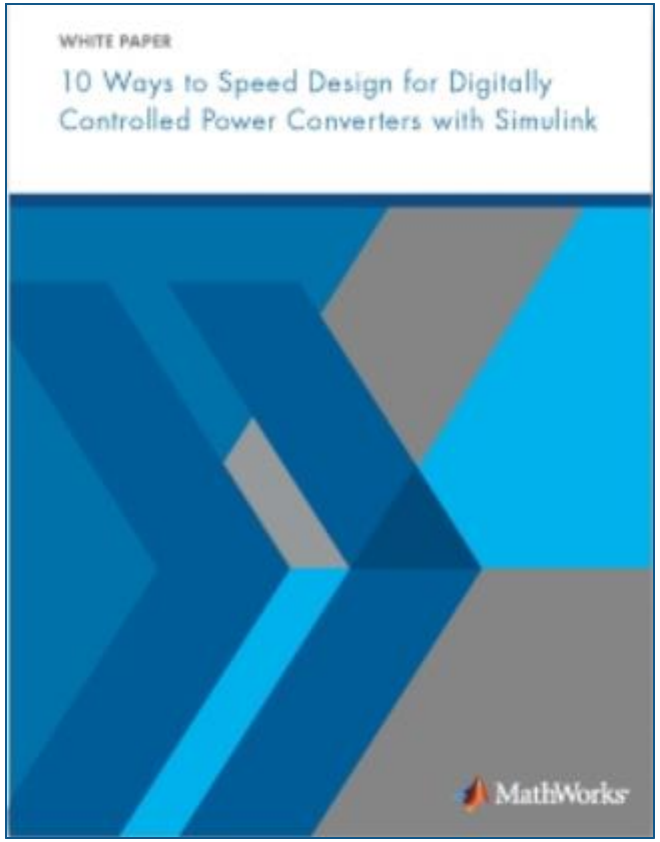
- Get **[power electronics control design trial package]** with necessary tools for desktop modeling, simulation, control design

- Visit the demo booth on:

Motor Control and Power Conversion with TI MCUs

- Read White Paper

10 Ways to Speed up Power Conversion Control Design with Simulink



Motor Control Modeling and Simulation Using MATLAB and Simulink

Topics Covered:

- Simulink as a Platform for System and Plant Modeling
- Modeling and Simulation Electrical Systems Using Simscape
- System Analysis and Controller Design
- Control Algorithm Development for Three-Phase Motors

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LinkedIn: https://www.linkedin.com/in/naini-dawar-2b5856114/