Safety and Protection

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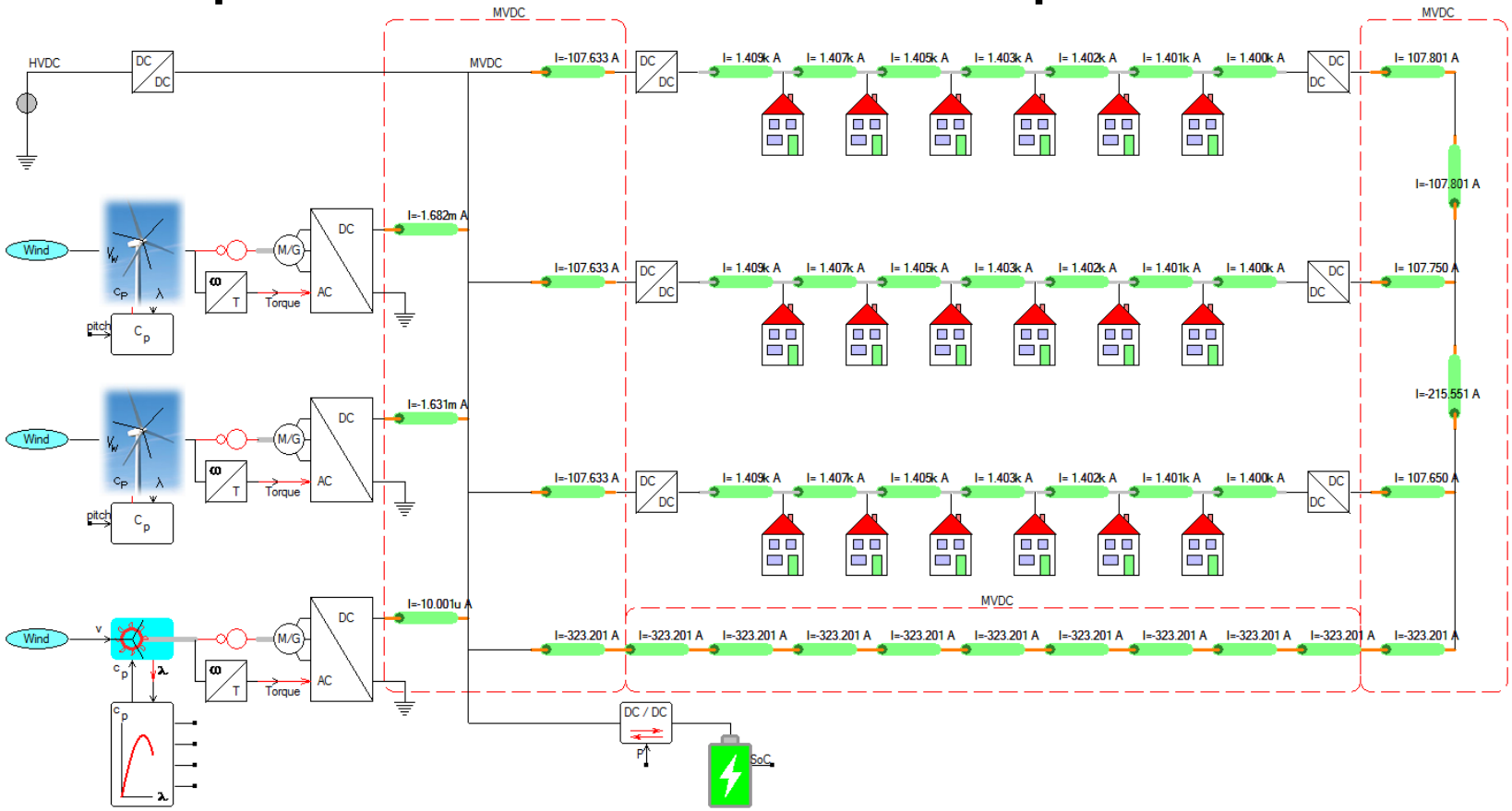
HHS / Simulation Research

www.caspoc.com/news/workshops/dctrees



Contents

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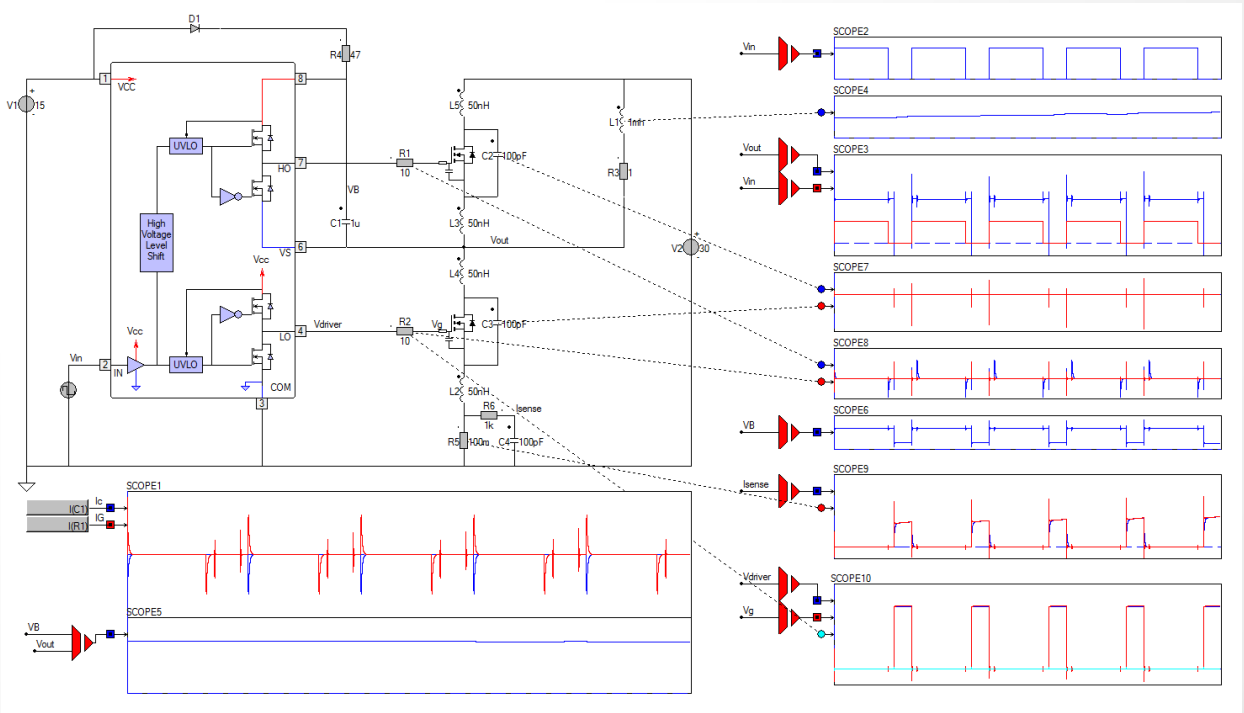
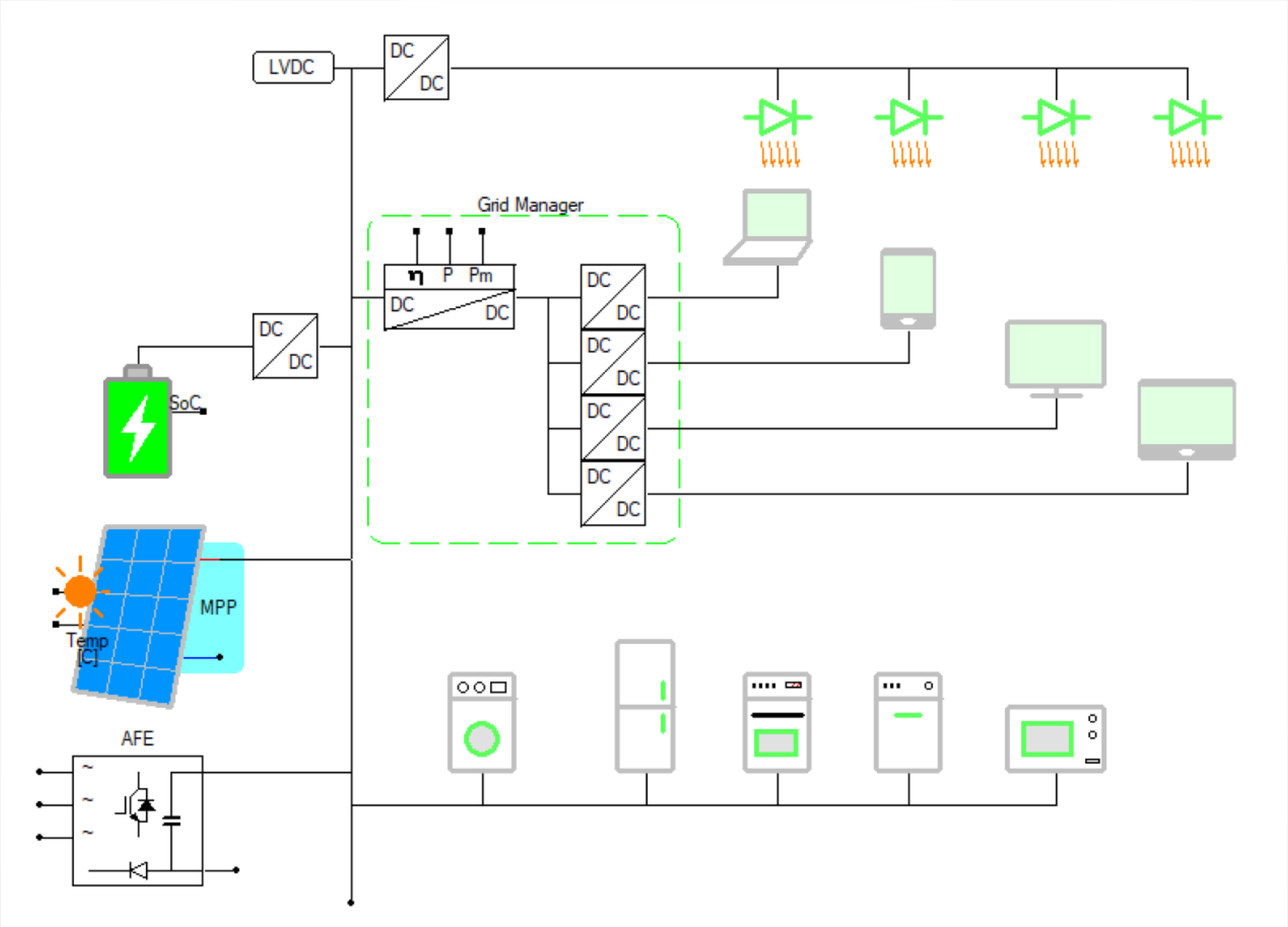
- Part I Configurations
  - DC grid architecture
  - Building Blocks
- Part II Protection and Safety
  - Short circuit protection
  - Earth connection
  - Inrush
  - Touch safety
  - Islanding
- Conclusion



Part I Configuration

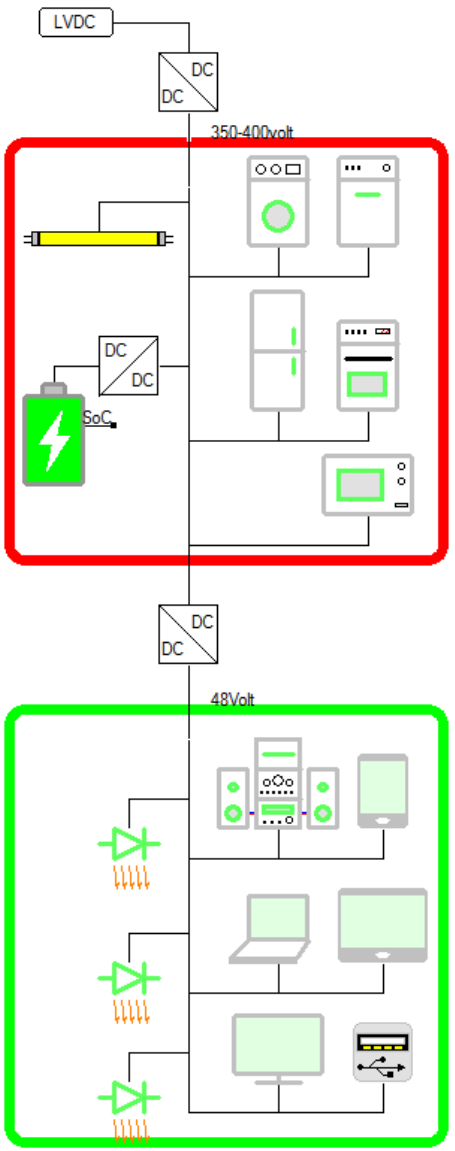
- Centralized DC
- Decentralized DC
- LVDC350-400V and LVDC-48V

PFC

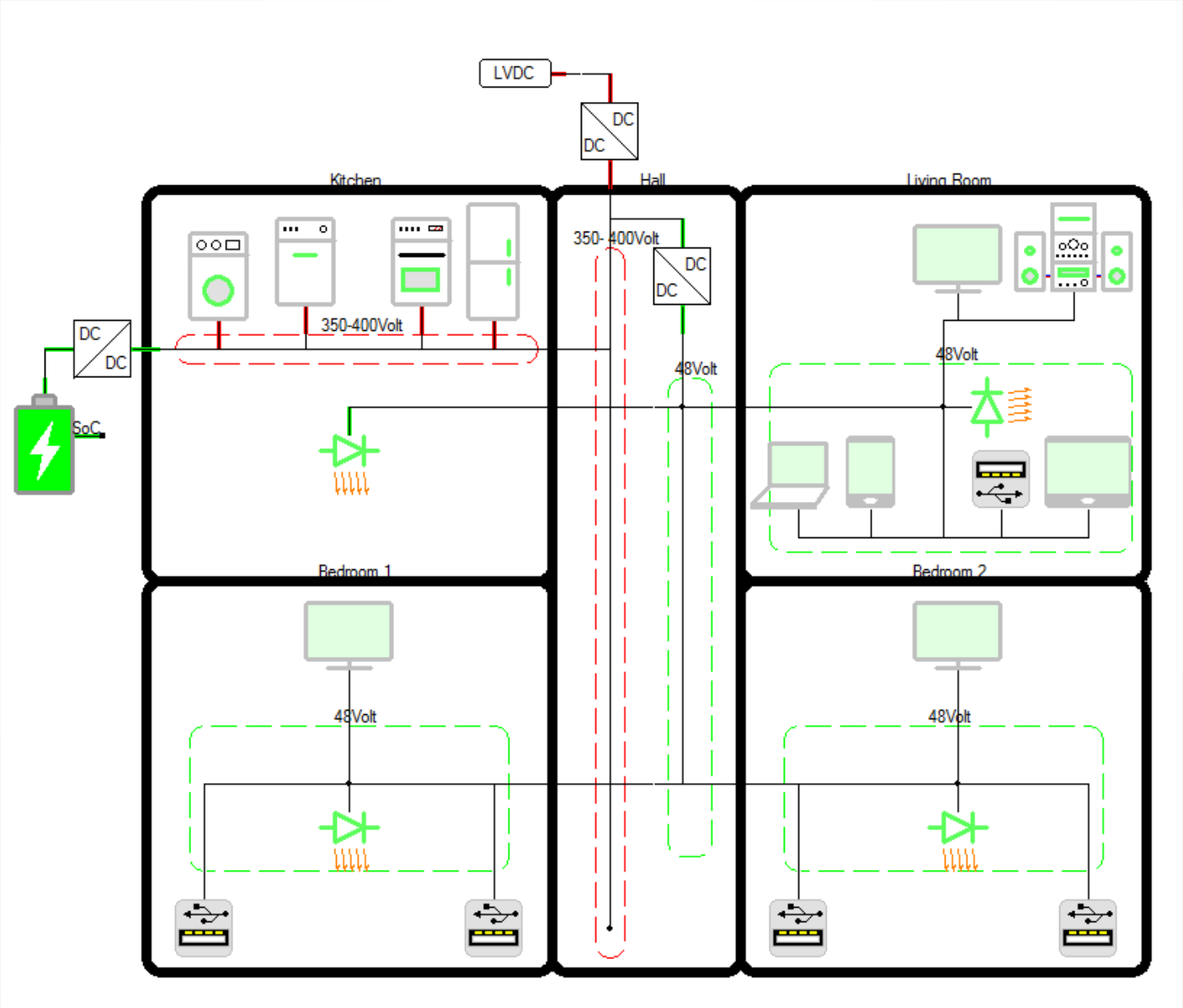

LVDC
DC
DC
Grid Manager
η
P
Pm
DC
DC
DC
DC
DC
DC
DC
DC
DC
DC
SoC
MPP
Temp
[C]
AFE

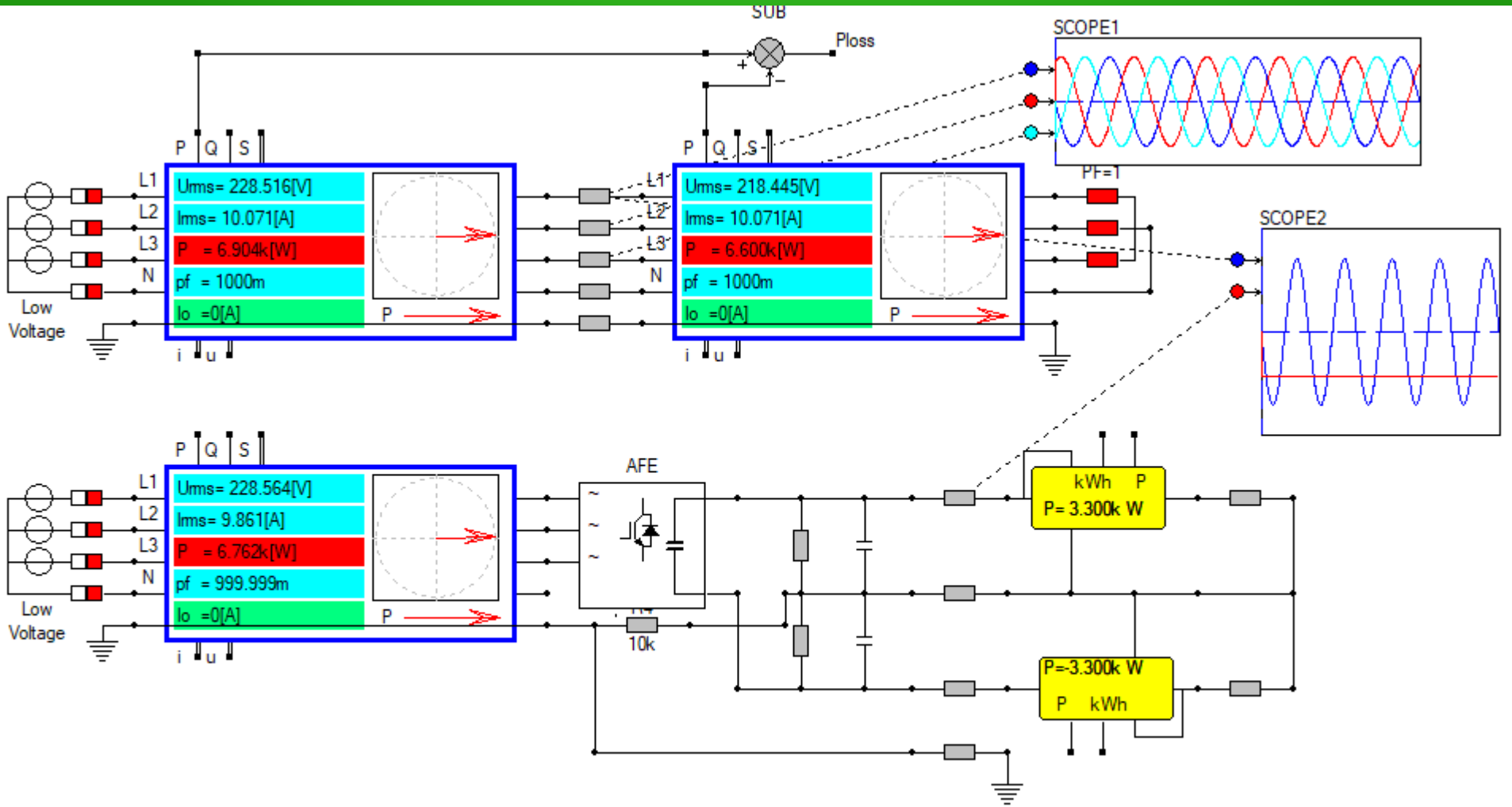
350-400volt – 48volt

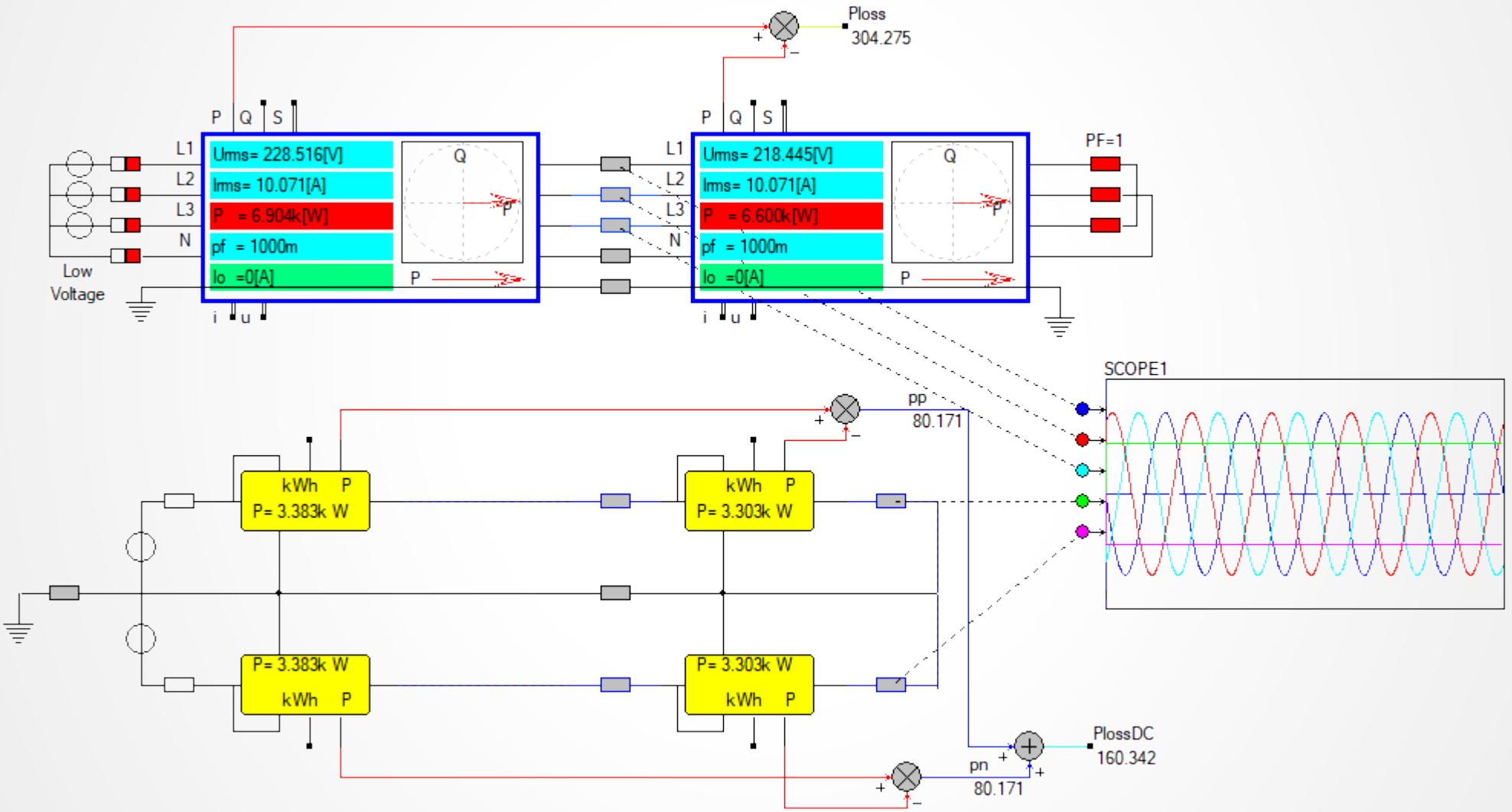
- 350-400 volt
  - Unipolar
  - Bipolar
- 48volt
  - Unipolar
- USB-C
  - 20volt 100Watt

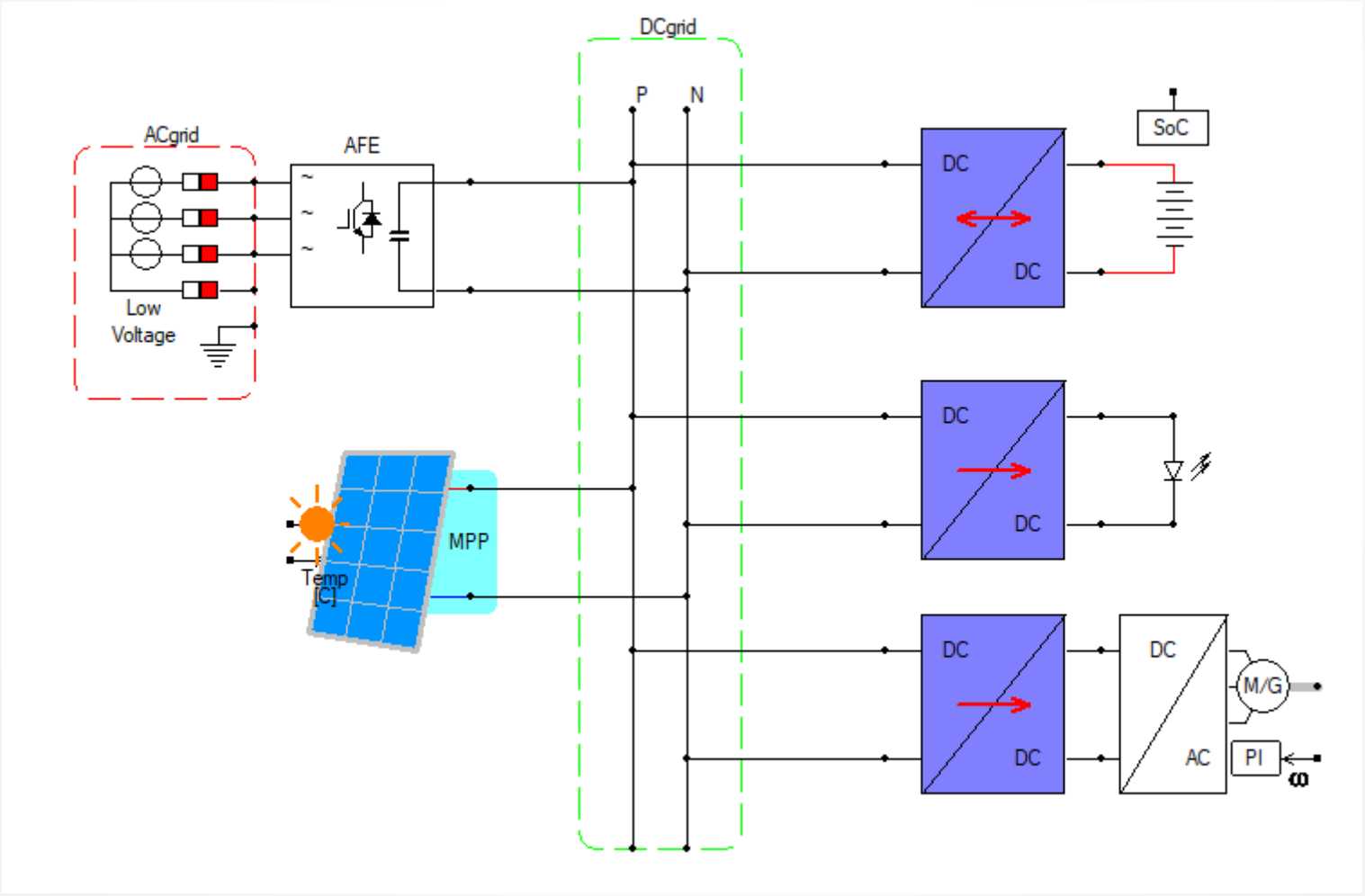


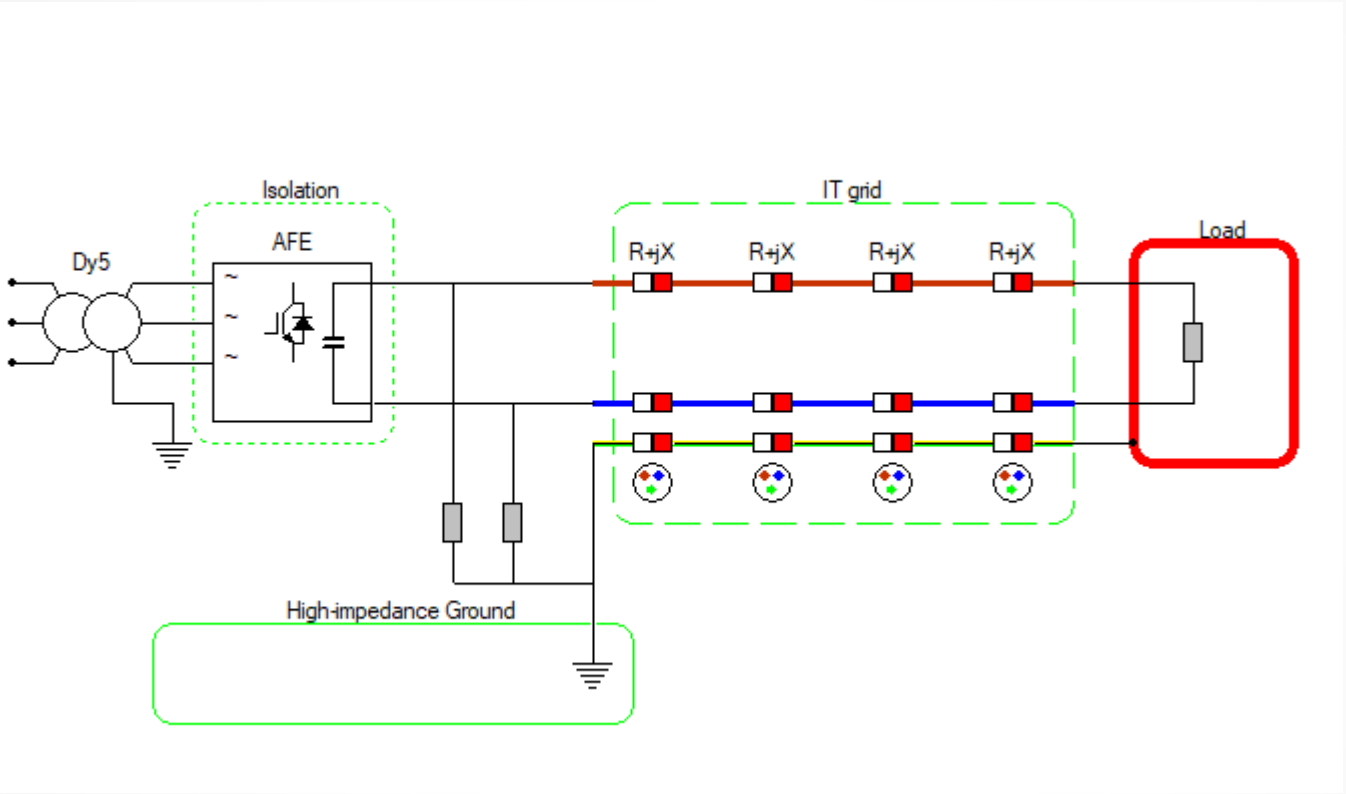
House – Dual Voltage



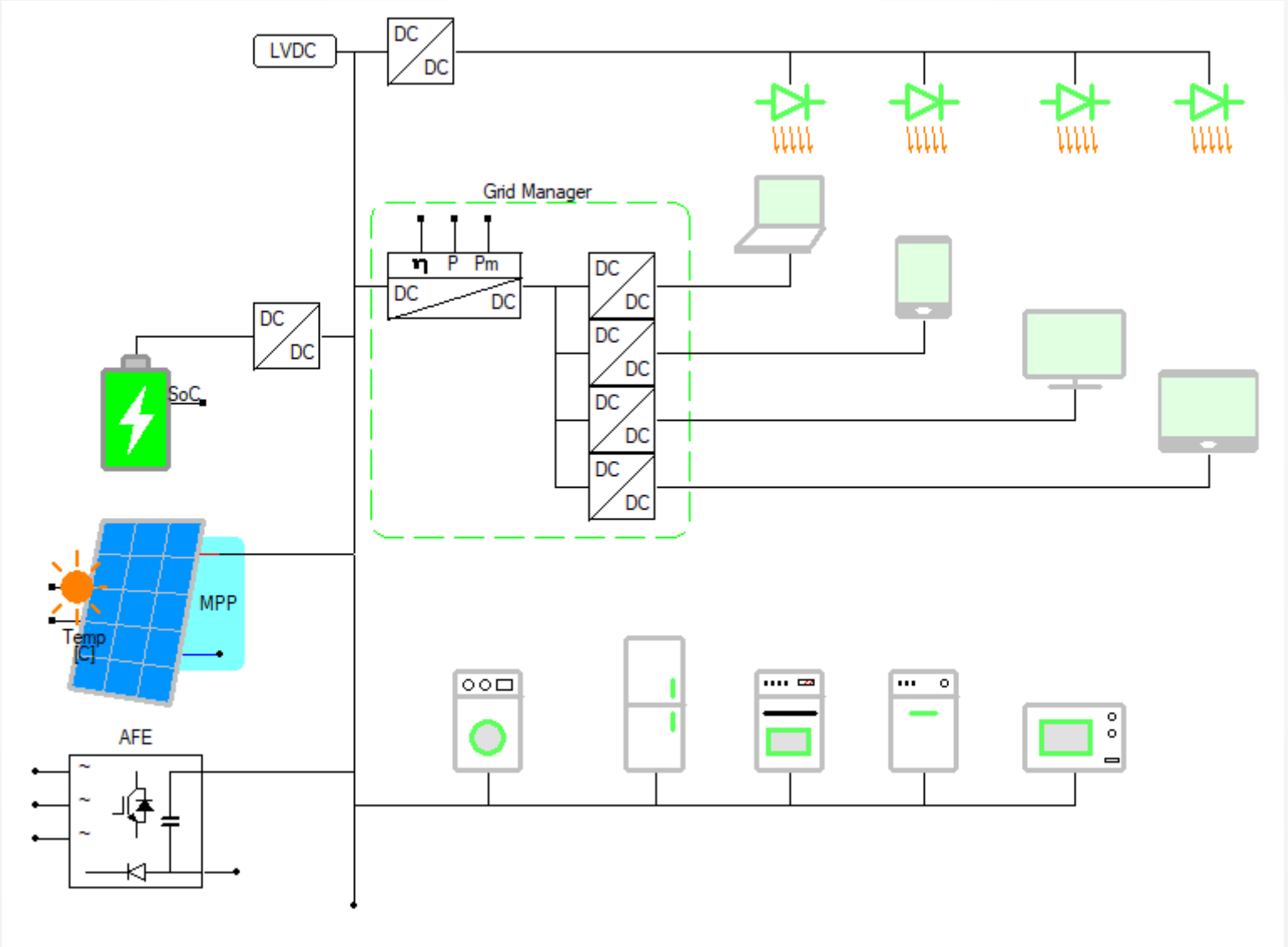

SUB
Ploss
SCOPE1
SCOPE2
PF=1
P Q S
L1
L2
L3
N
Low Voltage
Urms= 228.516[V]
Irms= 10.071[A]
P = 6.904k[W]
pf = 1000m
Io =0[A]
Urms= 218.445[V]
Irms= 10.071[A]
P = 6.600k[W]
pf = 1000m
Io =0[A]
Urms= 228.564[V]
Irms= 9.861[A]
P = 6.762k[W]
pf = 999.999m
Io =0[A]
AFE
10k
kWh P
P= 3.300k W
P=-3.300k W
P kWh


Ploss
304.275
P Q S
L1
L2
L3
N
Urms= 228.516[V]
Irms= 10.071[A]
P = 6.904k[W]
pf = 1000m
Io =0[A]
Low
Voltage
Urms= 218.445[V]
Irms= 10.071[A]
P = 6.600k[W]
PF=1
SCOPE1
pp
80.171
kWh P
P= 3.383k W
P= 3.303k W
pn
80.171
PlossDC
160.342


DCgrid
P
N
ACgrid
AFE
Low
Voltage
SoC
DC
DC
DC
DC
DC
DC
MPP
Temp
[C]
DC
AC
M/G
PI
ω

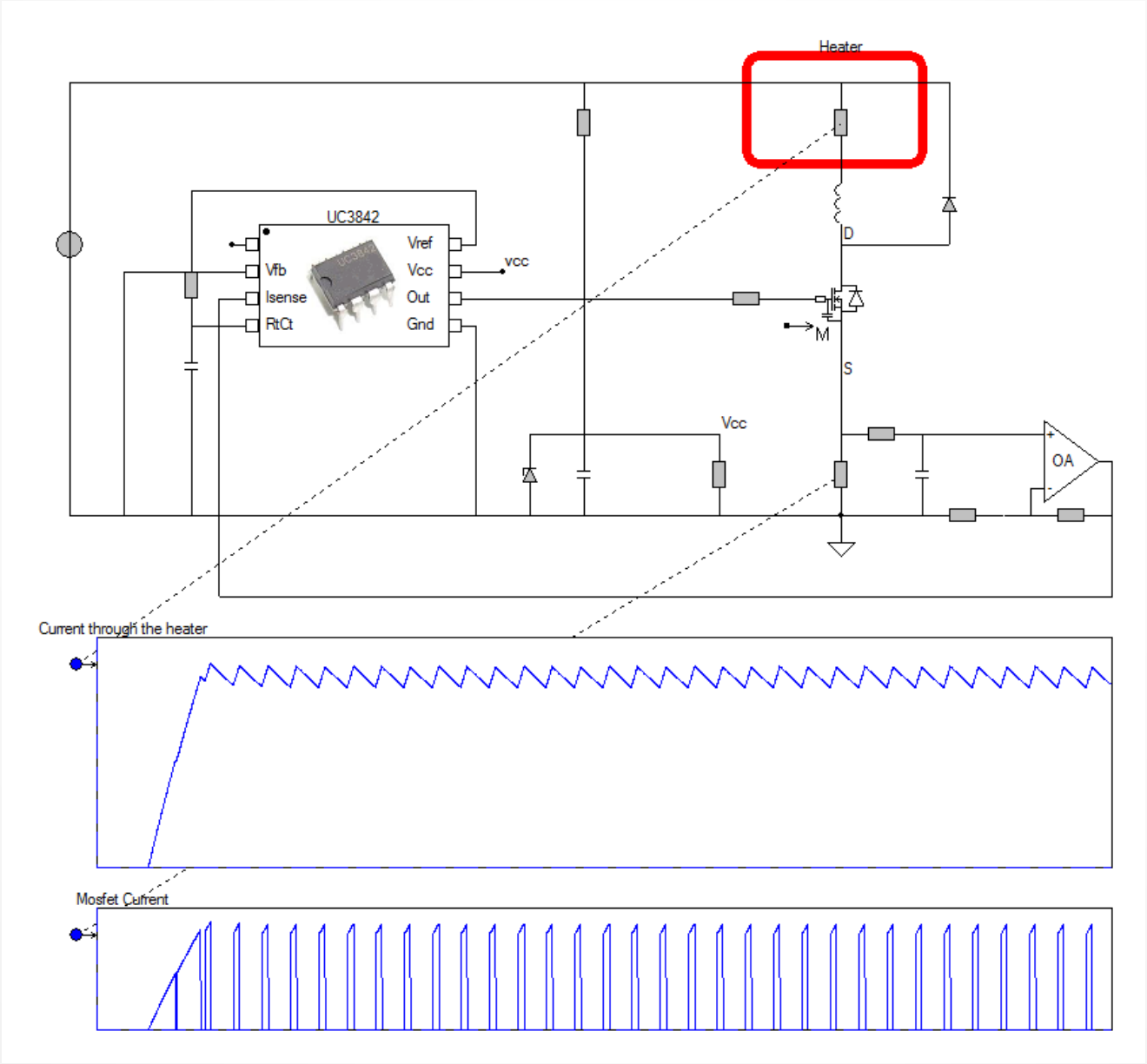

Isolation
AFE
Dy5
IT grid
R+jX
R+jX
R+jX
R+jX
Load
High-impedance Ground

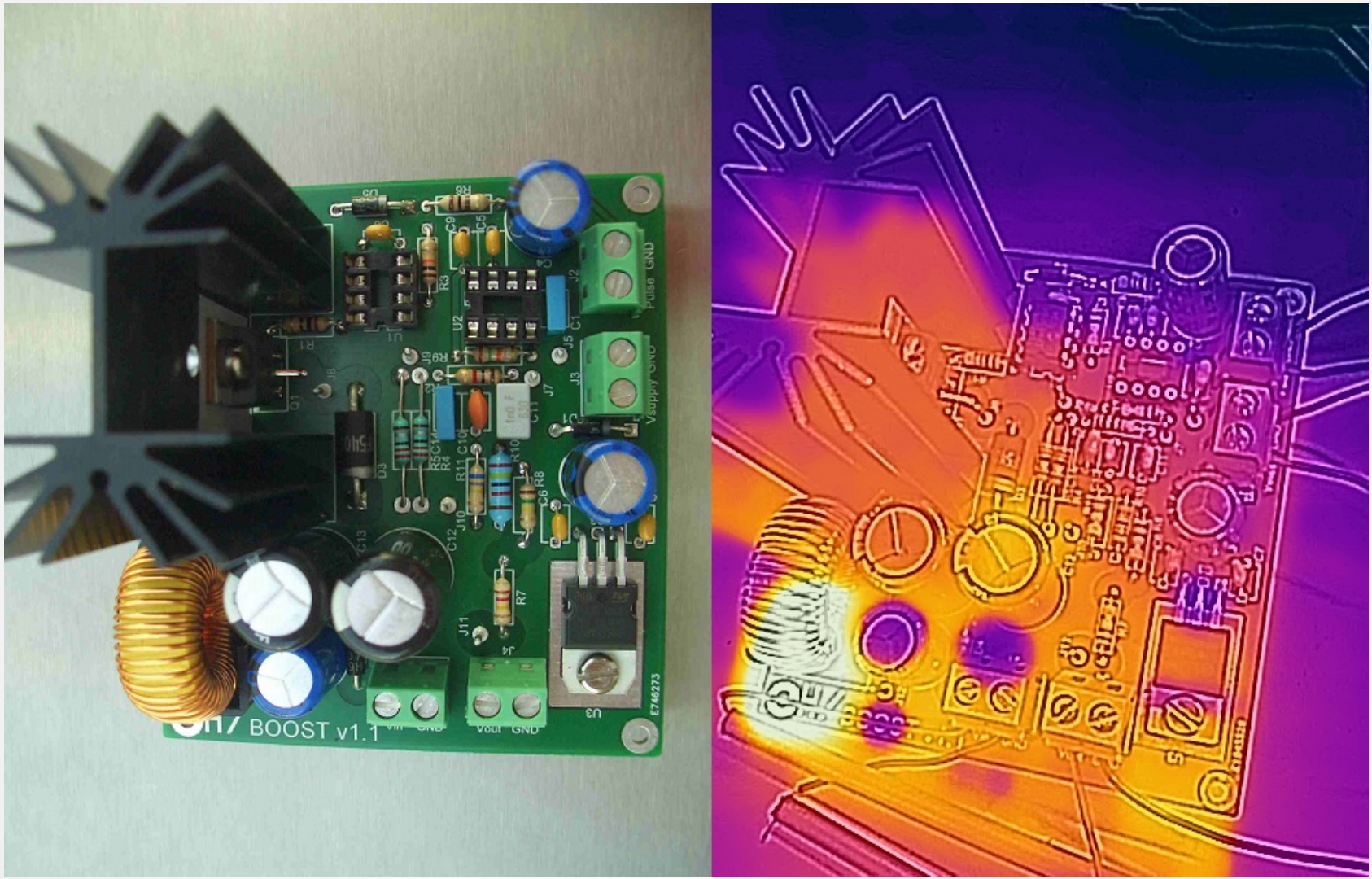
Grid manager



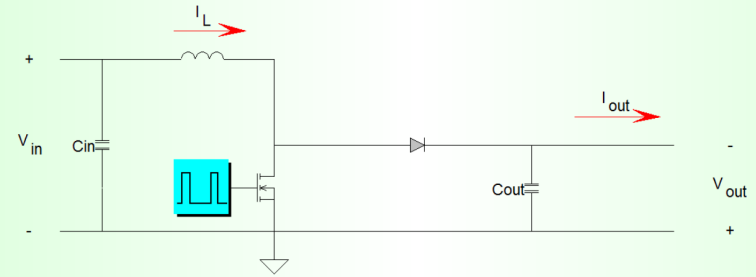
Part I Building blocks

- PFC- Single phase
- DCDC
  - Non-Isolated
    - Synchronous Buck
  - Isolated
    - Flyback
    - Dual Active Bridge [DAB]
- Rectifiers
- ACDC / DCAC
  - Active Front End [AFE]
  - Active Front End + Isolated DCDC


Heater
UC3842
Vfb
Isense
RtCt
Vref
Vcc
Out
Gnd
vcc
D
M
S
Vcc
OA
Current through the heater
Mosfet Current


BOOST v1.1
Vout GND
Vsupply GND
Pulse GND
E746273

Caspoc



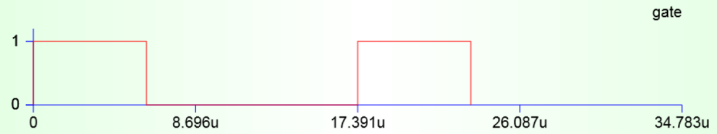
Input voltage	20	[V]
Output voltage	30	[V]
Output current	0.551	[A]
Inductor current ripple	40	0..100[%]
Output voltag ripple	0.1	0..100[%]
Switching Frequency	57.5	[kHz]
Diode forward voltage drop	0.7	[v]
Use predefined inductor value, (leave 0 for suggestion)	150	[µH]

Calculate

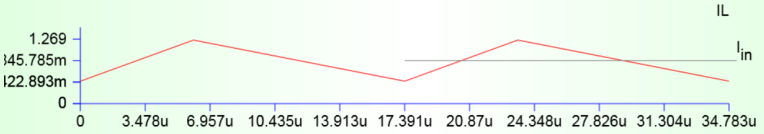
Grafiek | Outputfields | tab3 | tab4 | tab5

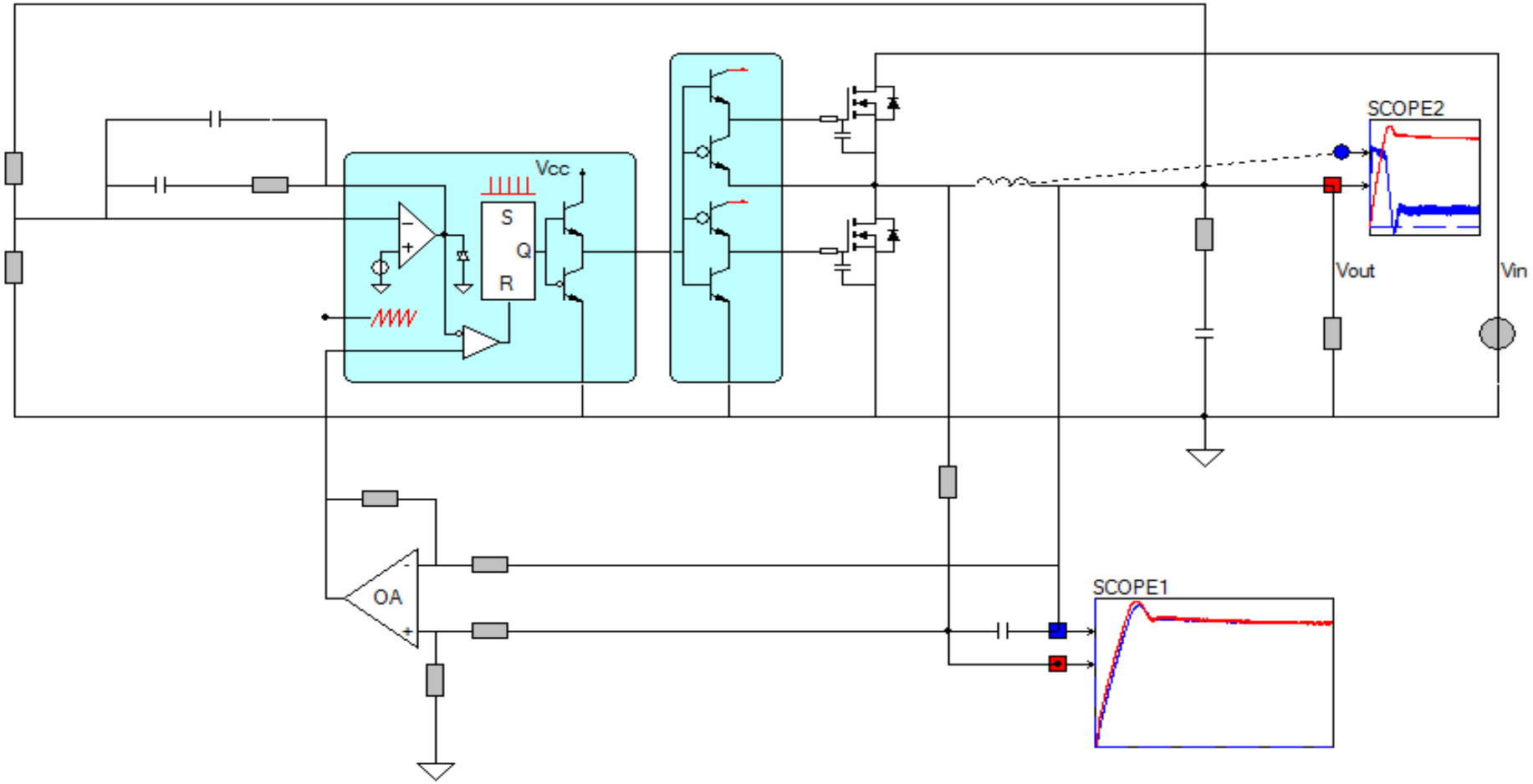
L=150[µH] C=58.56[µF] T_{on}=6.06[µs] T_{off}=17.39[µs] I_{peak}=1.25[A]
i_{ripple}=0.81[A] v_{ripple}=0.03[V] i_{in}=0.85[A]

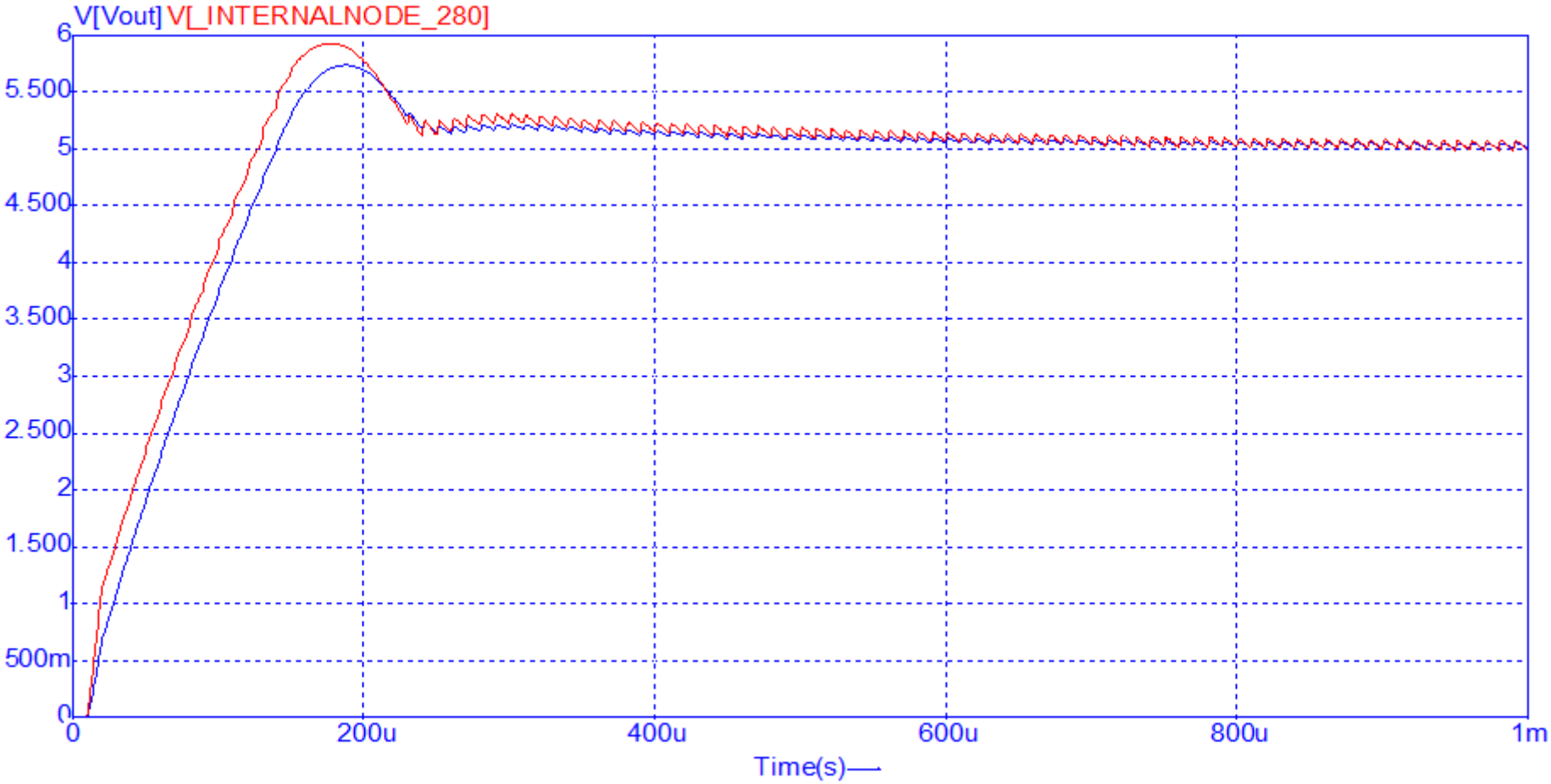
Gate signal for the Mosfet:

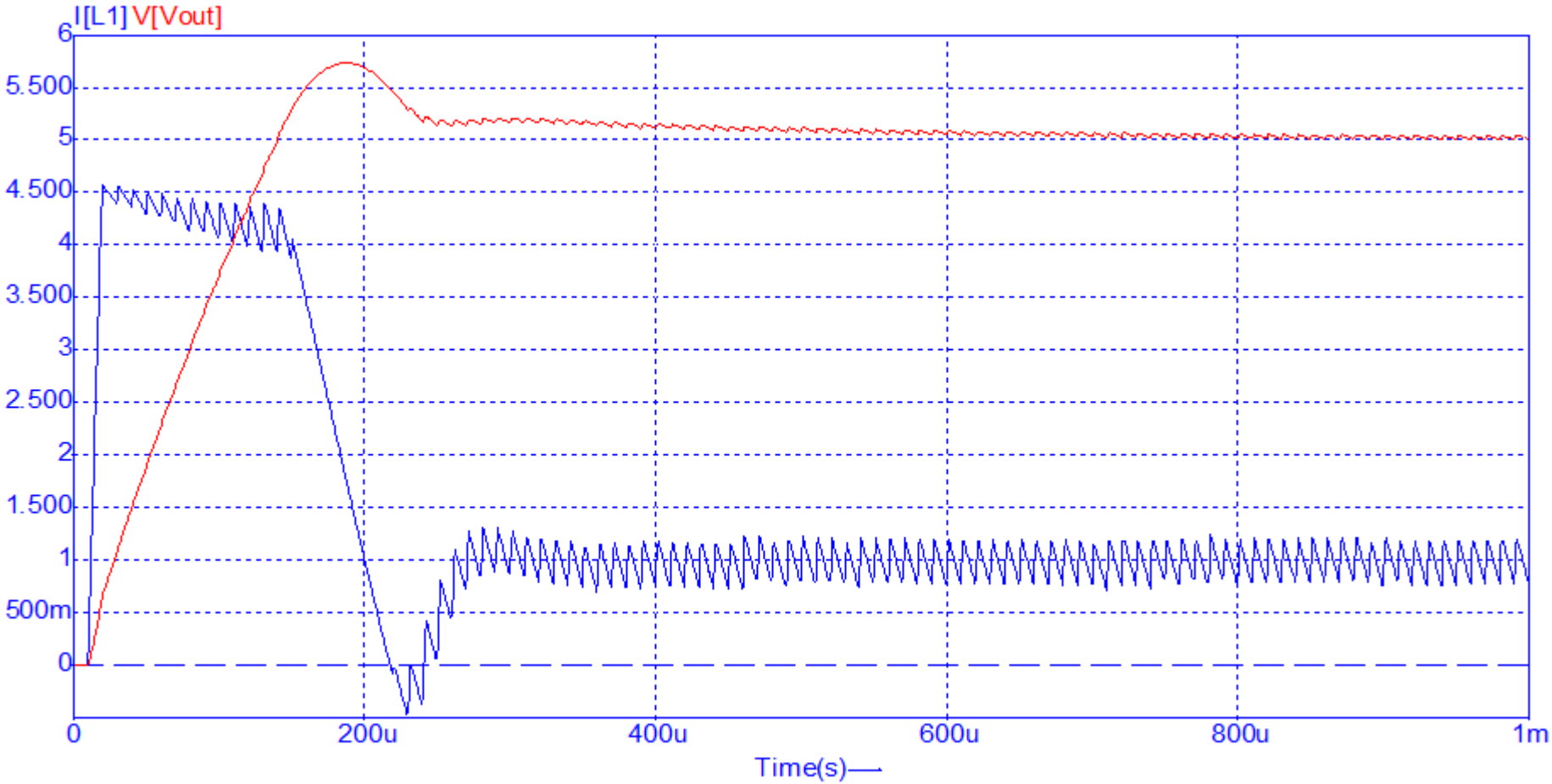


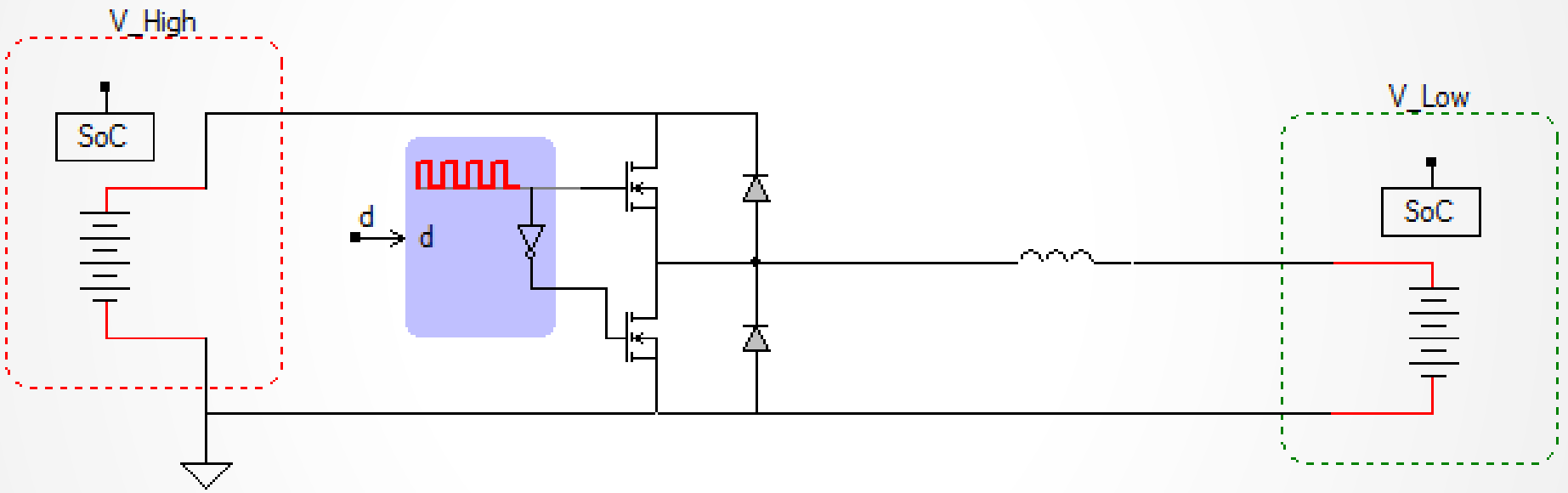
Current through the inductor:

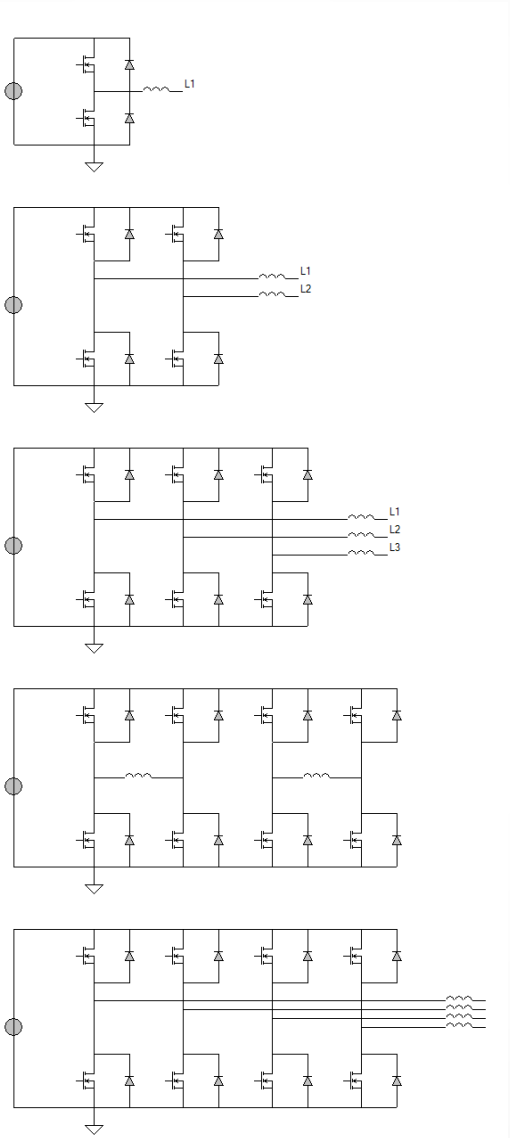


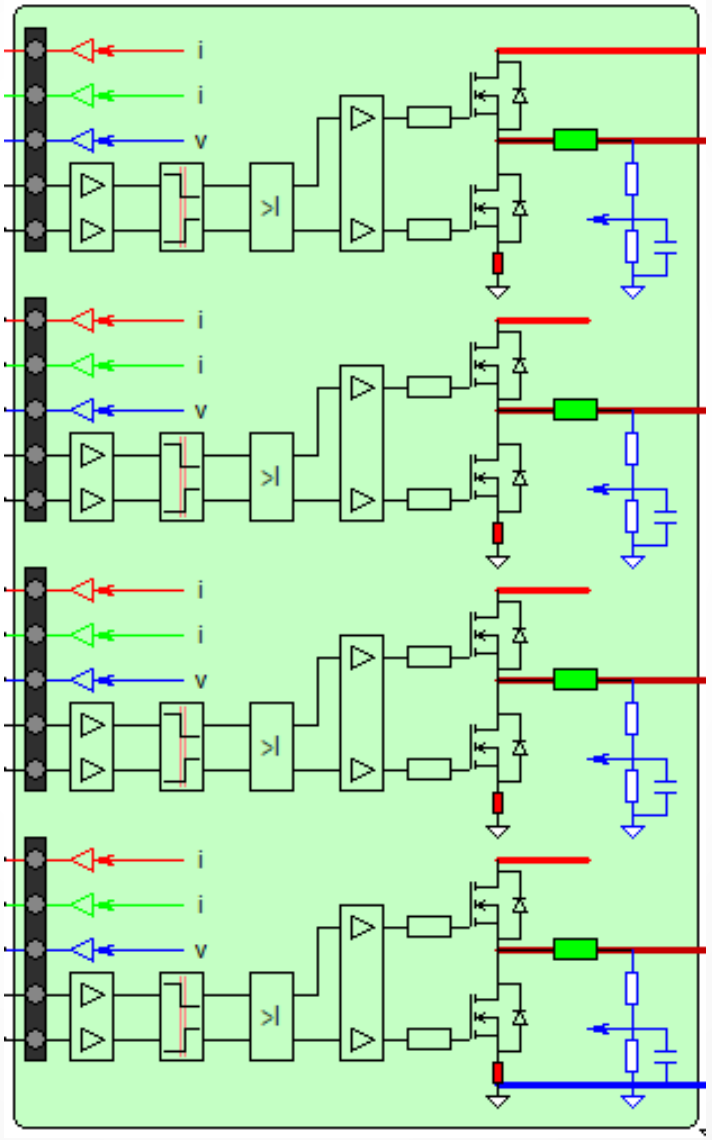

Vcc
S
Q
R
SCOPE2
Vout
Vin
OA
SCOPE1

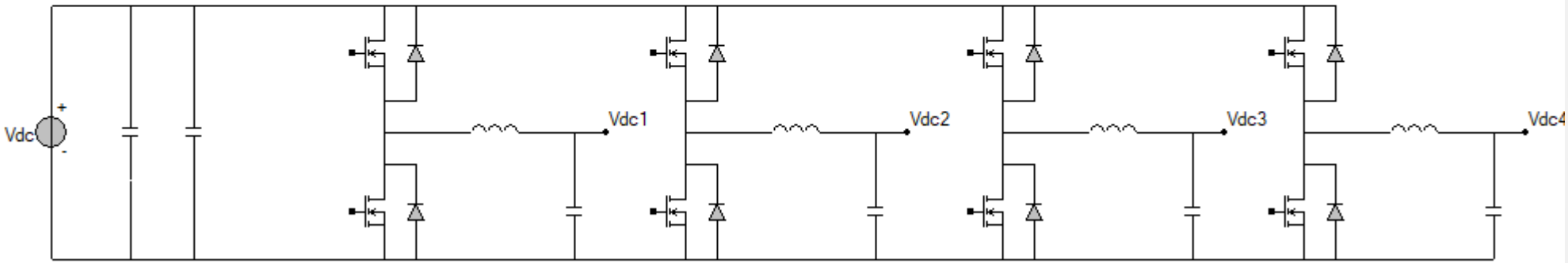

V[Vout]
V[_INTERNALNODE_280]
6
5.500
5
4.500
4
3.500
3
2.500
2
1.500
1
500m
0
0
200u
400u
600u
800u
1m
Time(s)

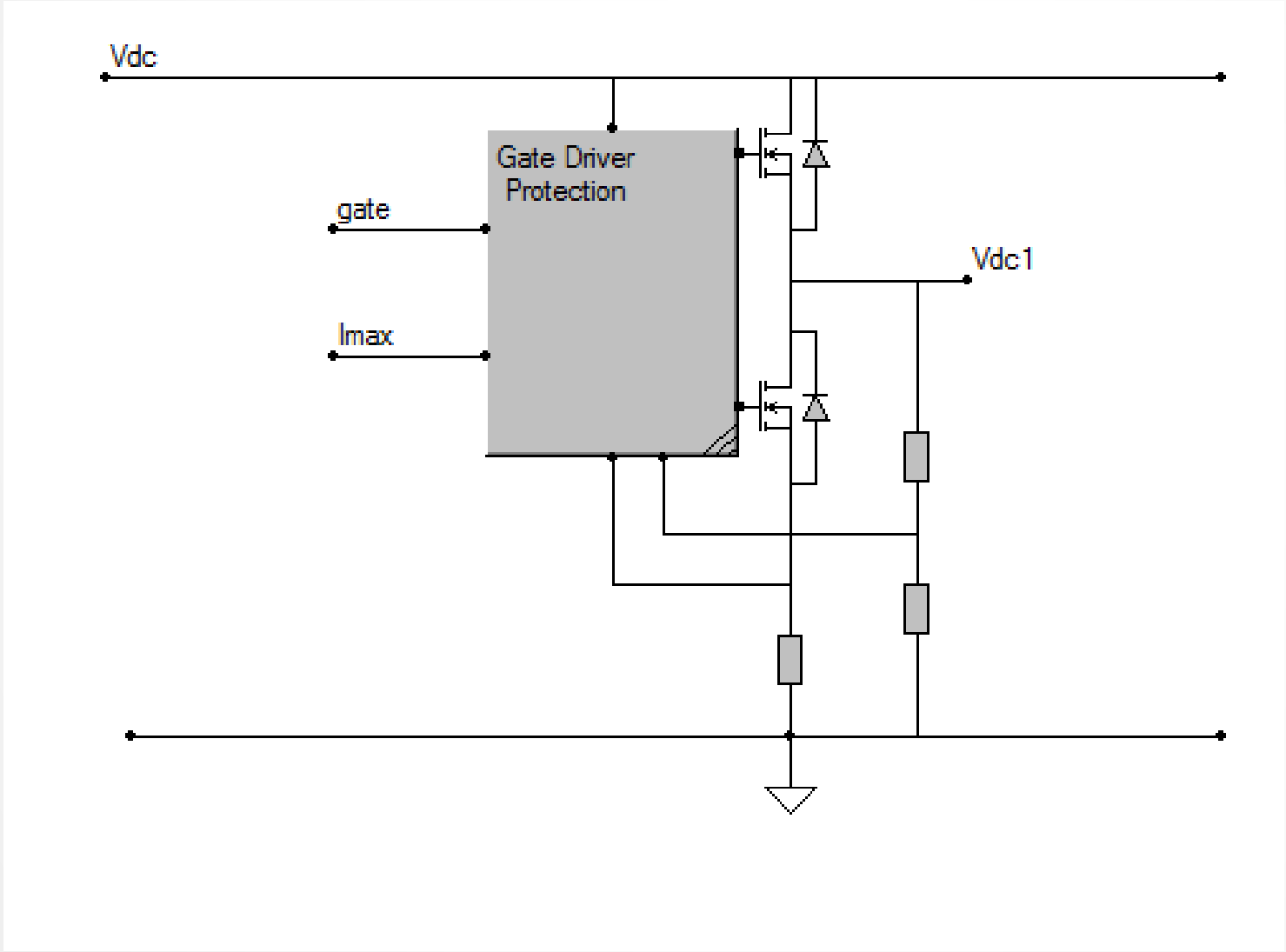

I[L1] V[Vout]
6
5.500
5
4.500
4
3.500
3
2.500
2
1.500
1
500m
0
0
200u
400u
600u
800u
1m
Time(s)

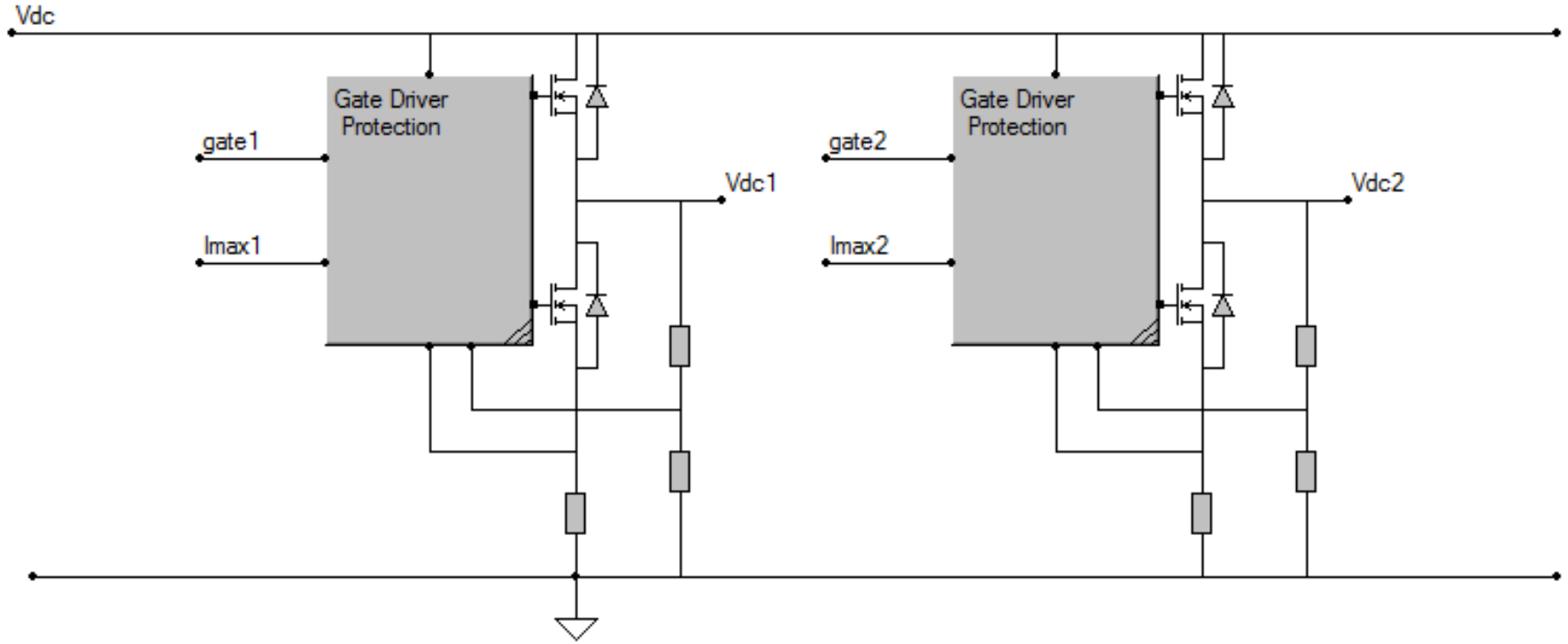

V_High
SoC
d
d
V_Low
SoC

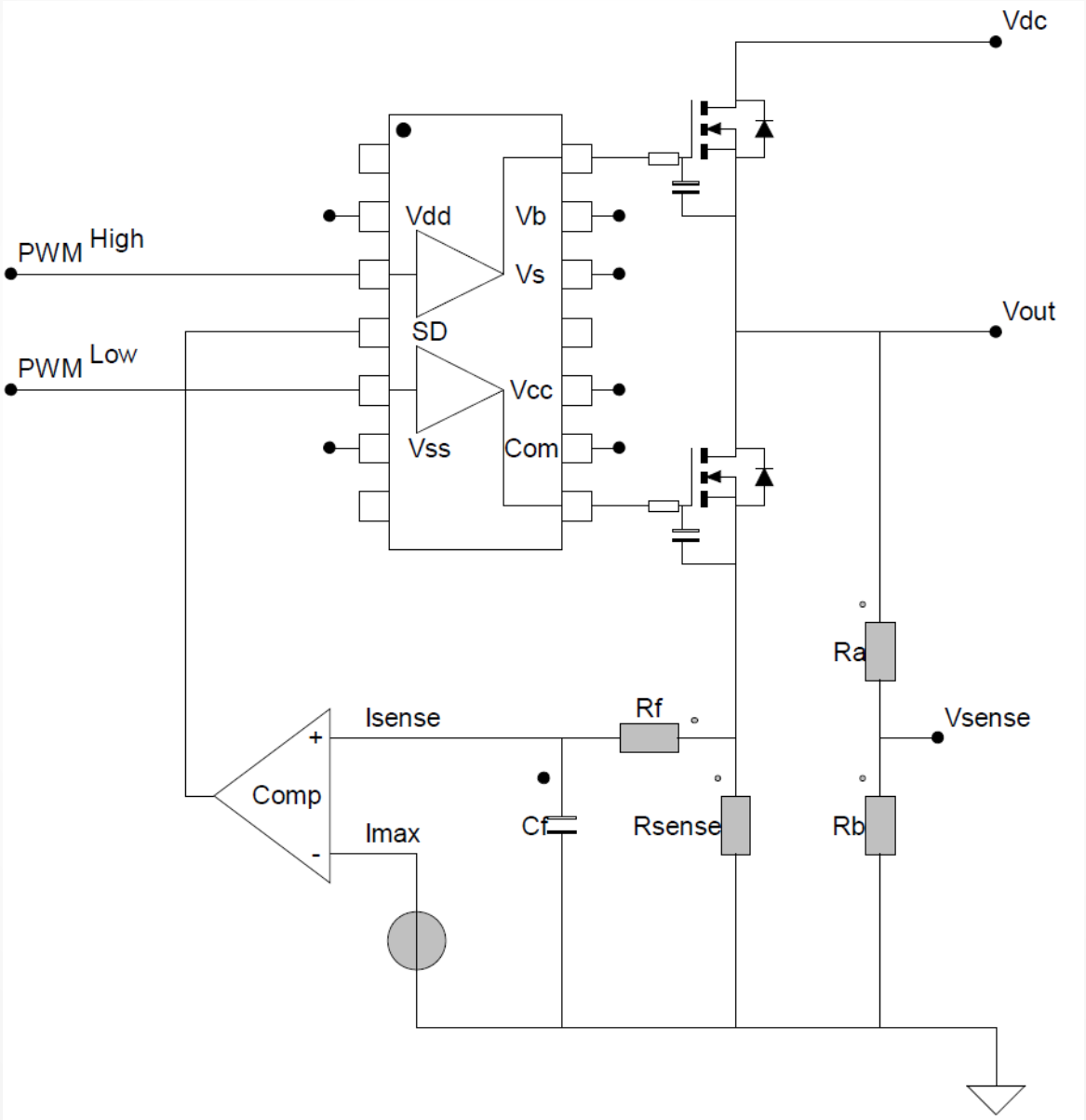

L1
L1
L2
L1
L2
L3

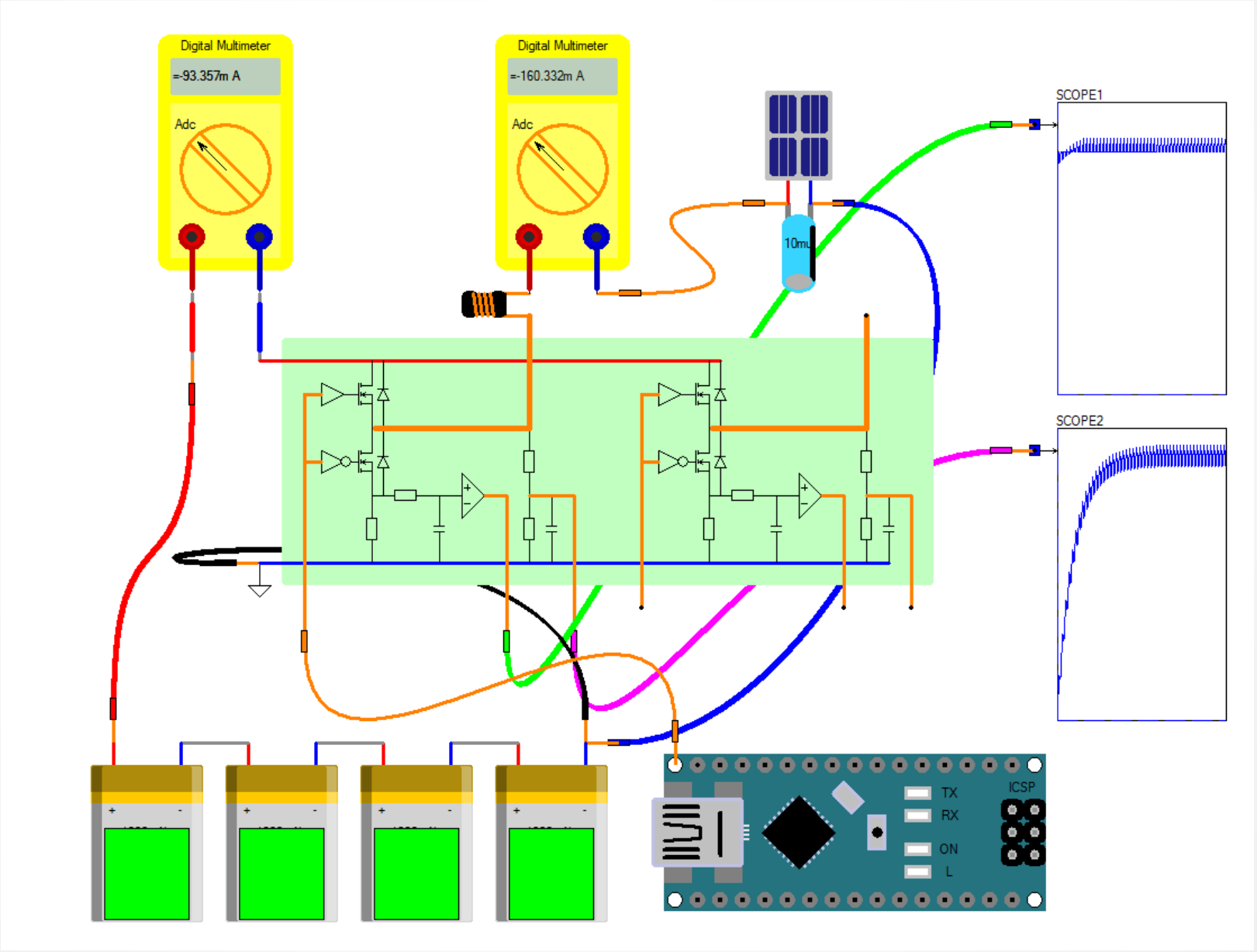

i
i
v
>|
i
i
v
>|
i
i
v
>|
i
i
v
>|

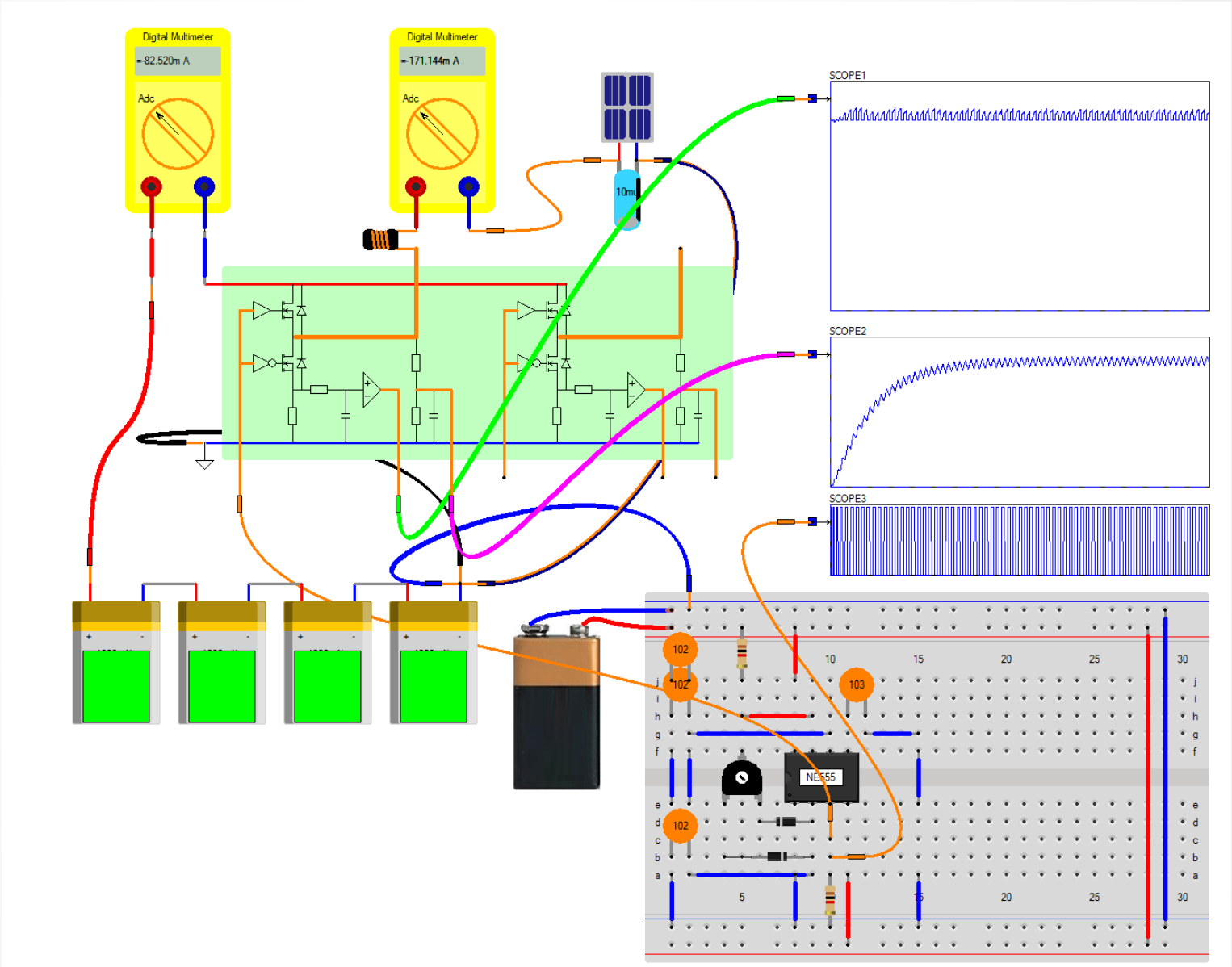

Vdc
+
-
Vdc1
Vdc2
Vdc3
Vdc4

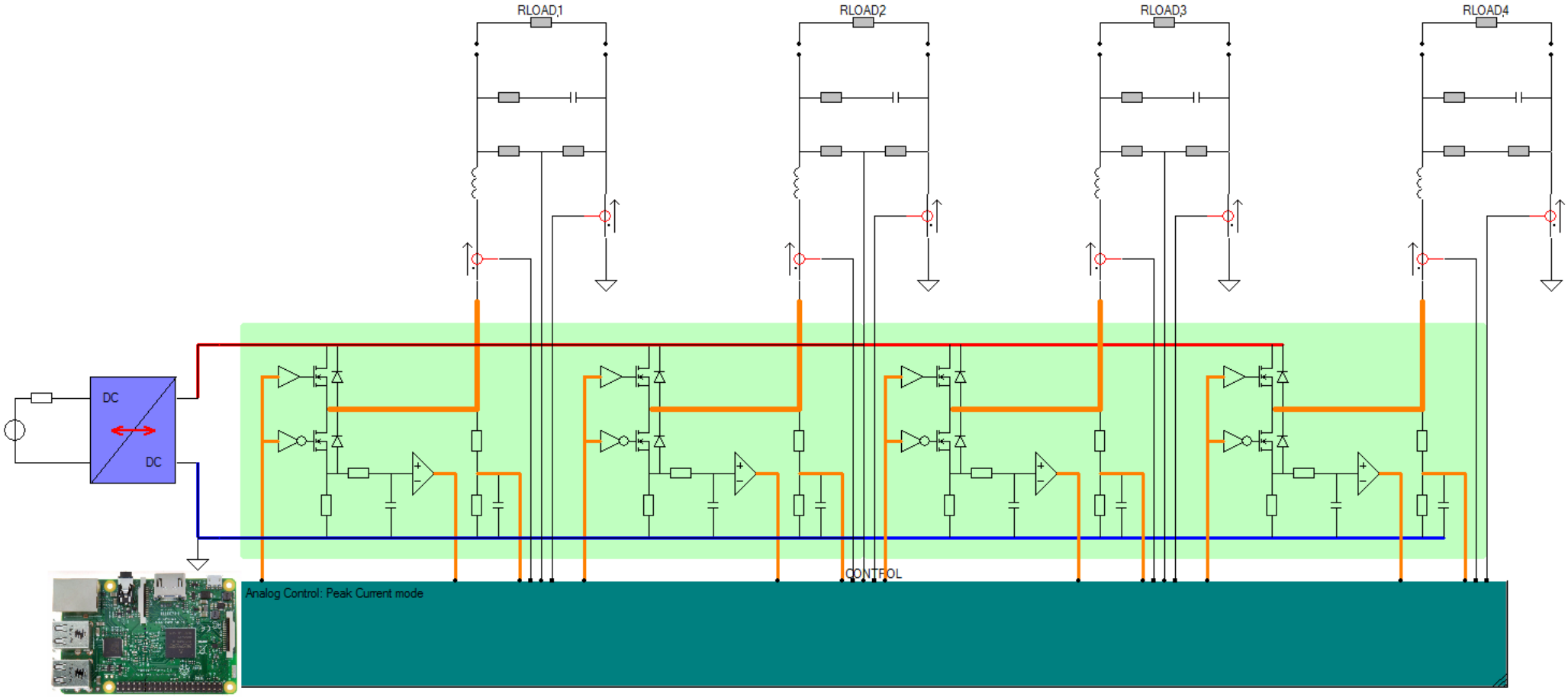

Vdc
Gate Driver
Protection
gate
Imax
Vdc1

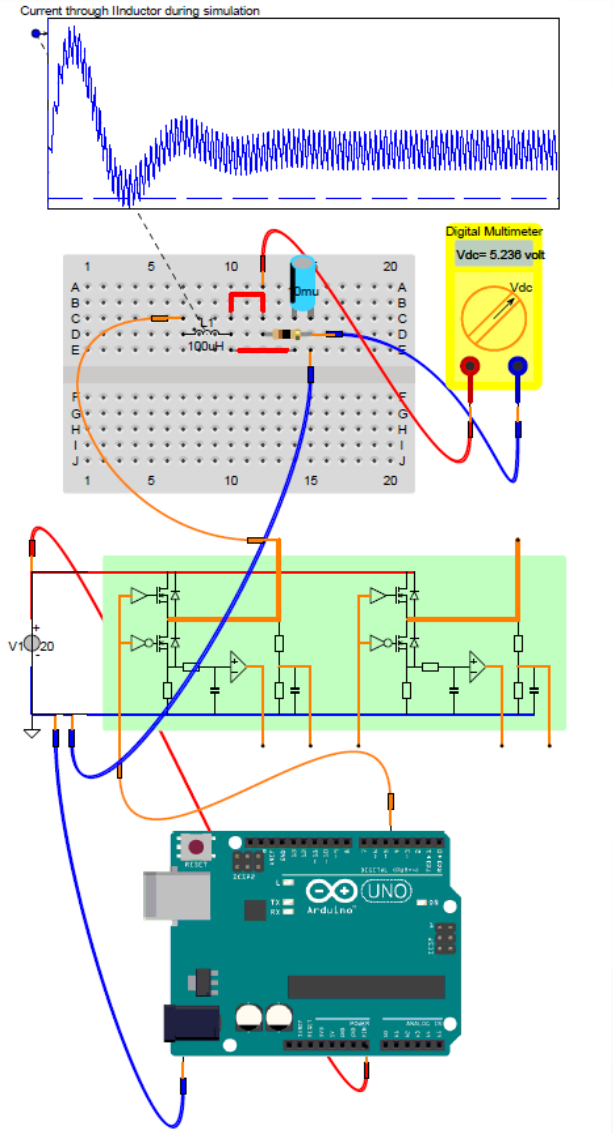

Vdc
Gate Driver
Protection
gate1
Imax1
Vdc1
Gate Driver
Protection
gate2
Imax2
Vdc2

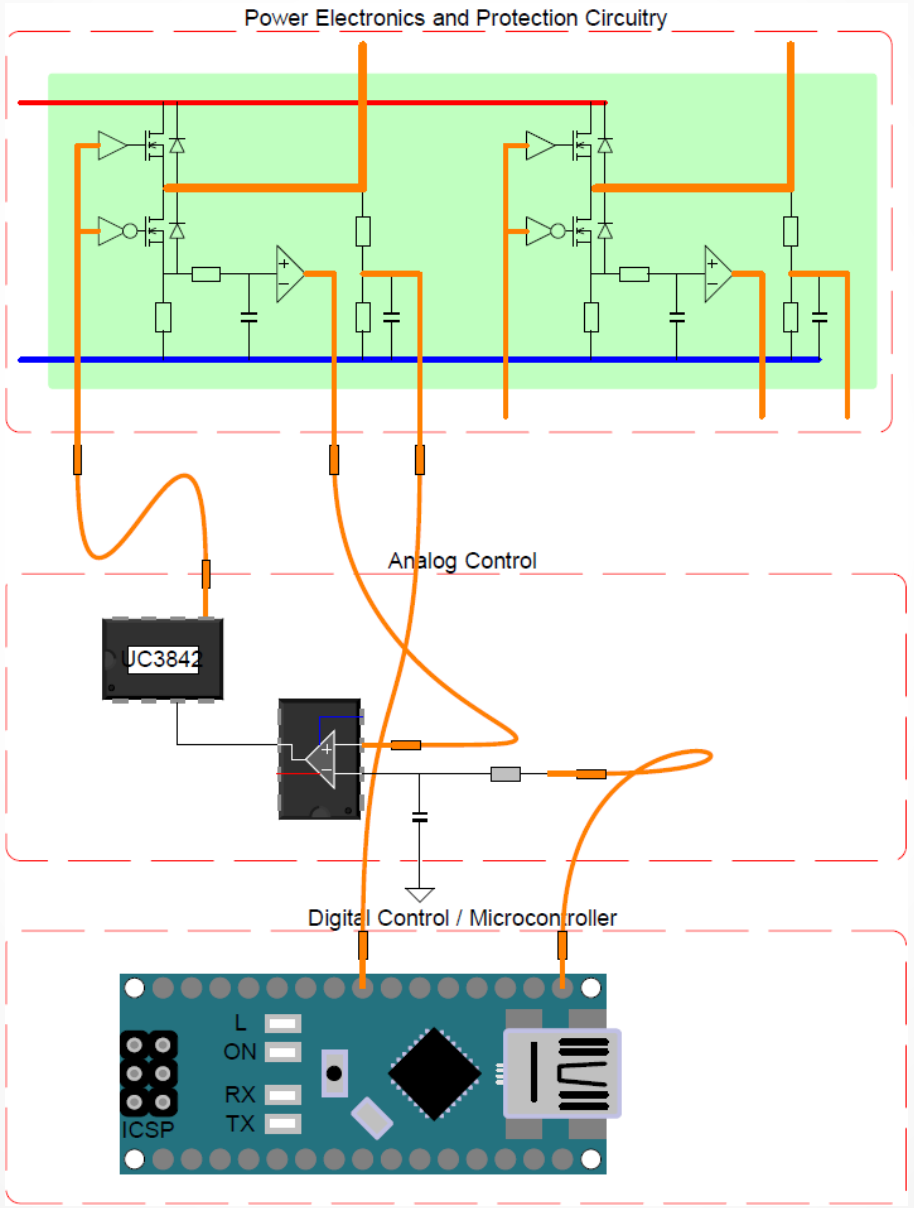

Vdc
Vdd
Vb
PWM High
Vs
Vout
SD
PWM Low
Vcc
Vss
Com
Ra
Isense
Rf
Vsense
+
Comp
Cf
Rsense
Rb
Imax
-


Digital Multimeter
=-93.357m A
Adc
Digital Multimeter
=-160.332m A
Adc
10mu
SCOPE1
SCOPE2
TX
RX
ON
L
ICSP

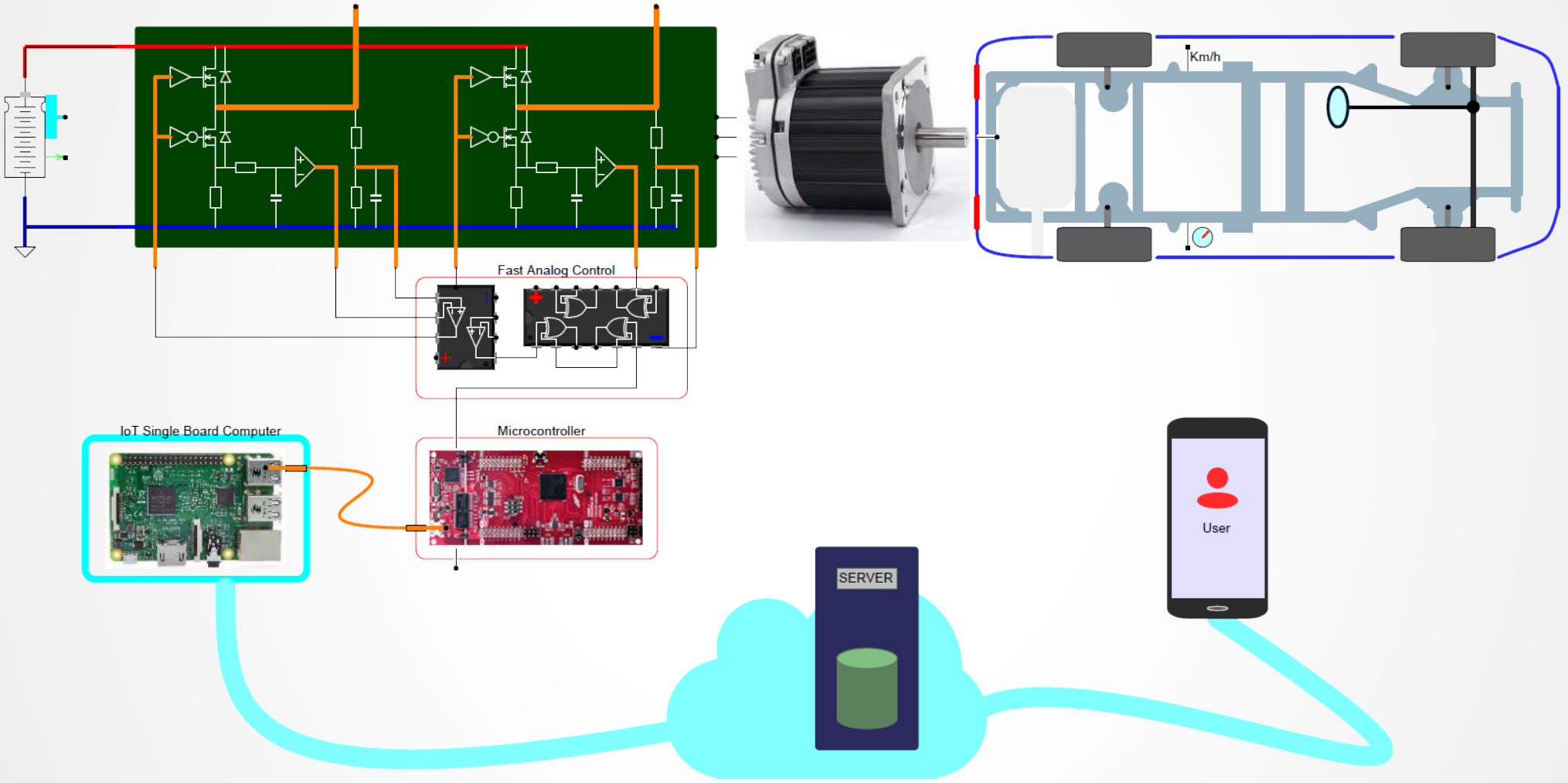

Digital Multimeter
=-82.520m A
Adc
Digital Multimeter
=-171.144m A
Adc
10mΩ
SCOPE1
SCOPE2
SCOPE3
102
102
103
NE555
102

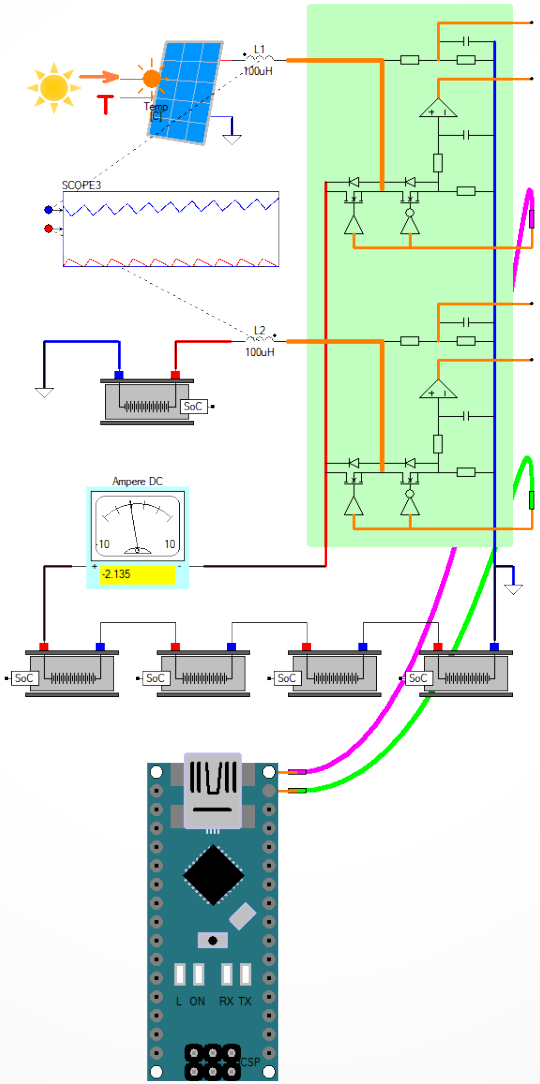

RLOAD1
RLOAD2
RLOAD3
RLOAD4
DC
DC
CONTROL
Analog Control: Peak Current mode

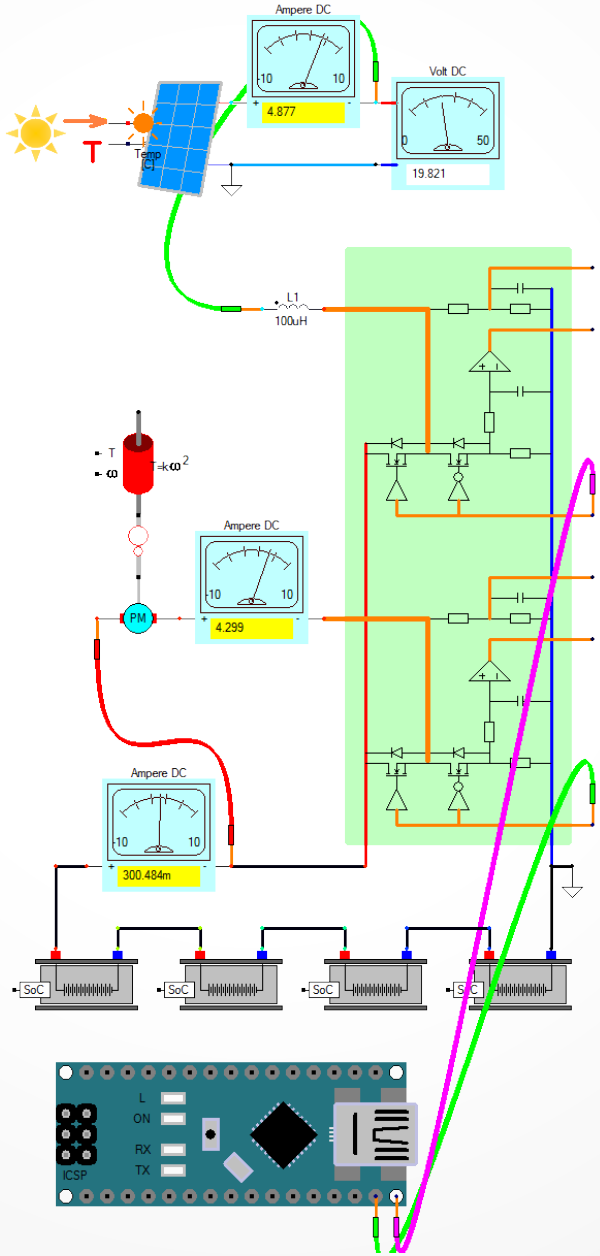

Current through IInductor during simulation
Digital Multimeter
Vdc= 5.236 volt
Vdc
L1
100uH
Dmu
V1
20
UNO
Arduino

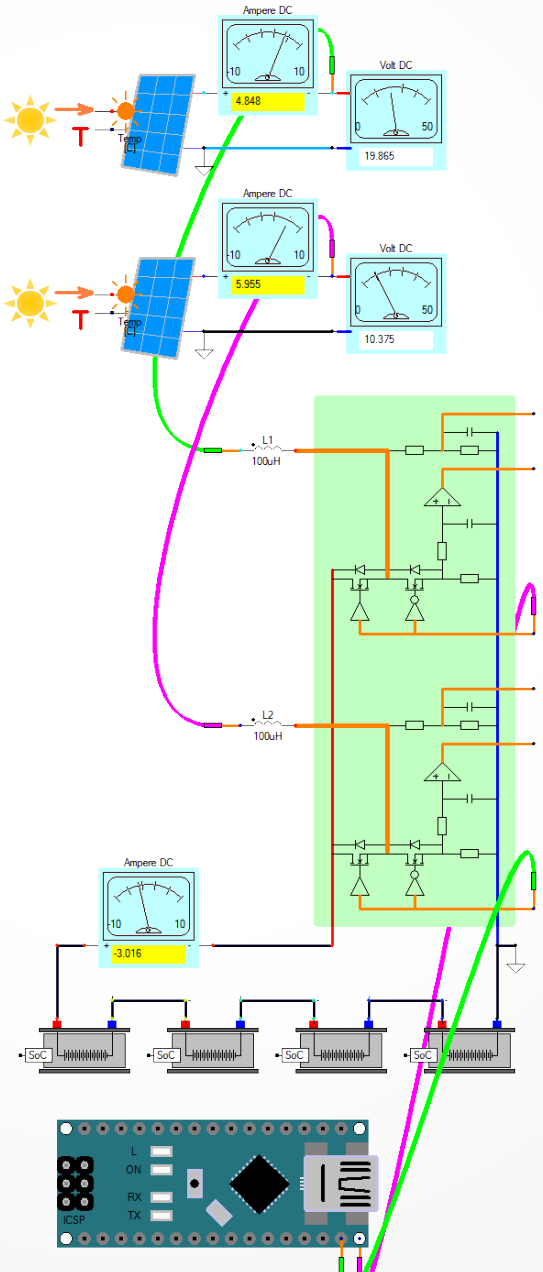

Power Electronics and Protection Circuitry
Analog Control
UC3842
Digital Control / Microcontroller
L
ON
RX
TX
ICSP

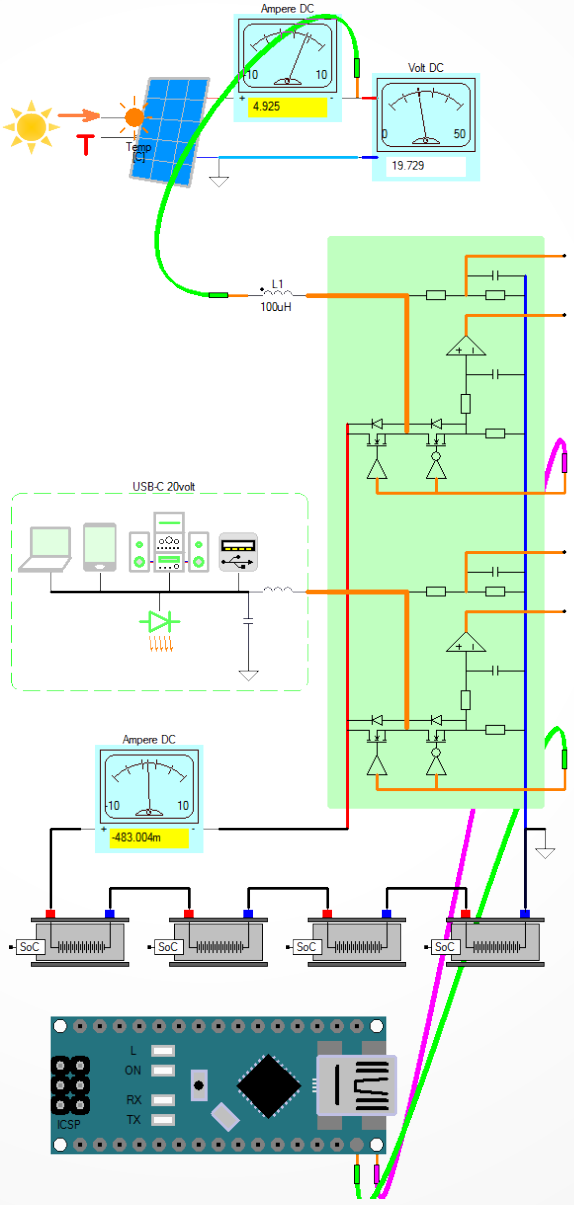
IoT


Km/h
Fast Analog Control
IoT Single Board Computer
Microcontroller
SERVER
User

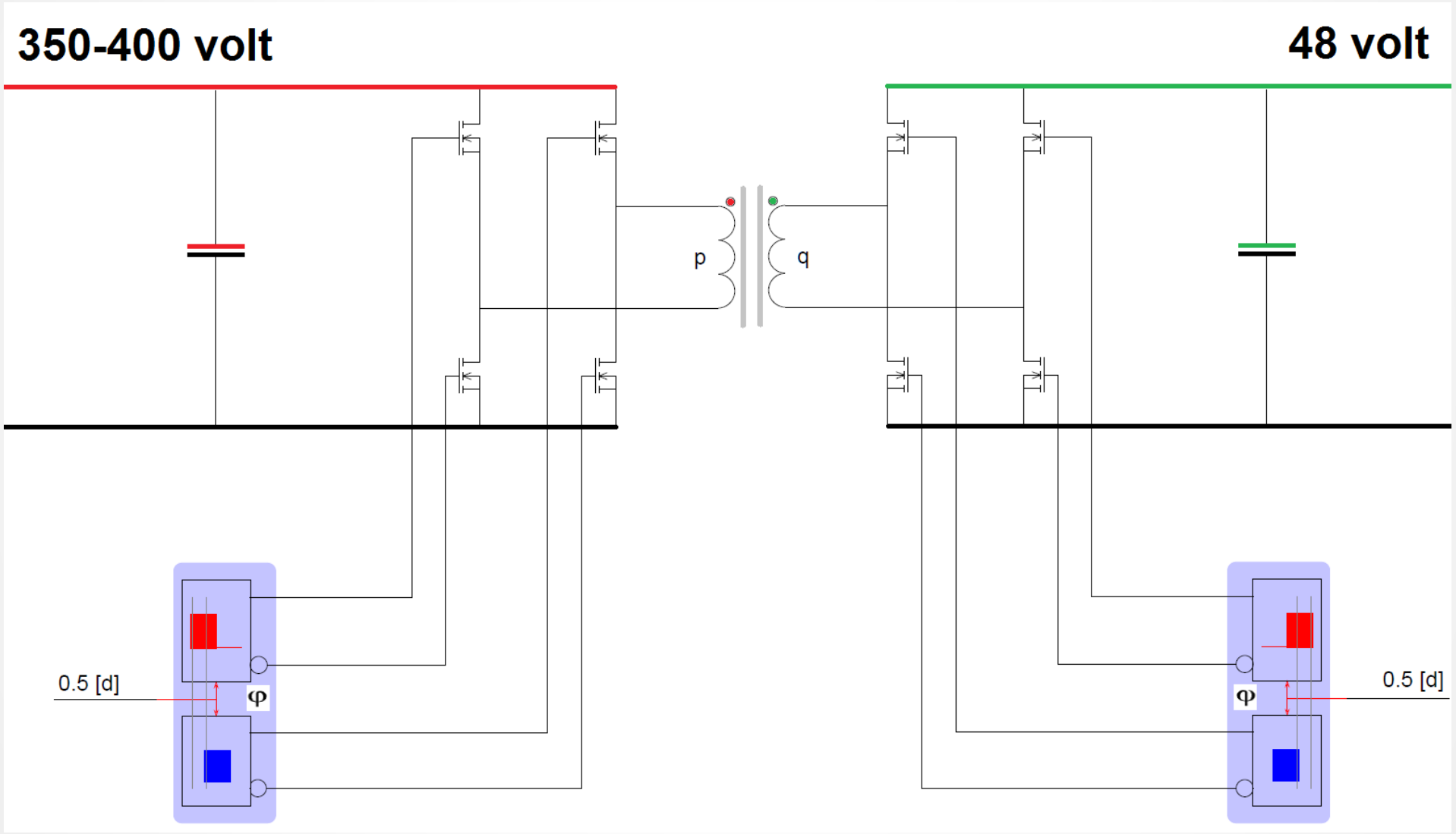

T
Temp
L1
100uH
SCOPE3
L2
100uH
SoC
Ampere DC
-10
10
-2.135
SoC
SoC
SoC
SoC
L ON RX TX
ESP


Ampere DC
4.877
Volt DC
19.821
T
Temp
L1
100uH
T
ω
T=kω²
PM
Ampere DC
4.299
Ampere DC
300.484m
SoC
SoC
SoC
SoC
L
ON
RX
TX
ICSP

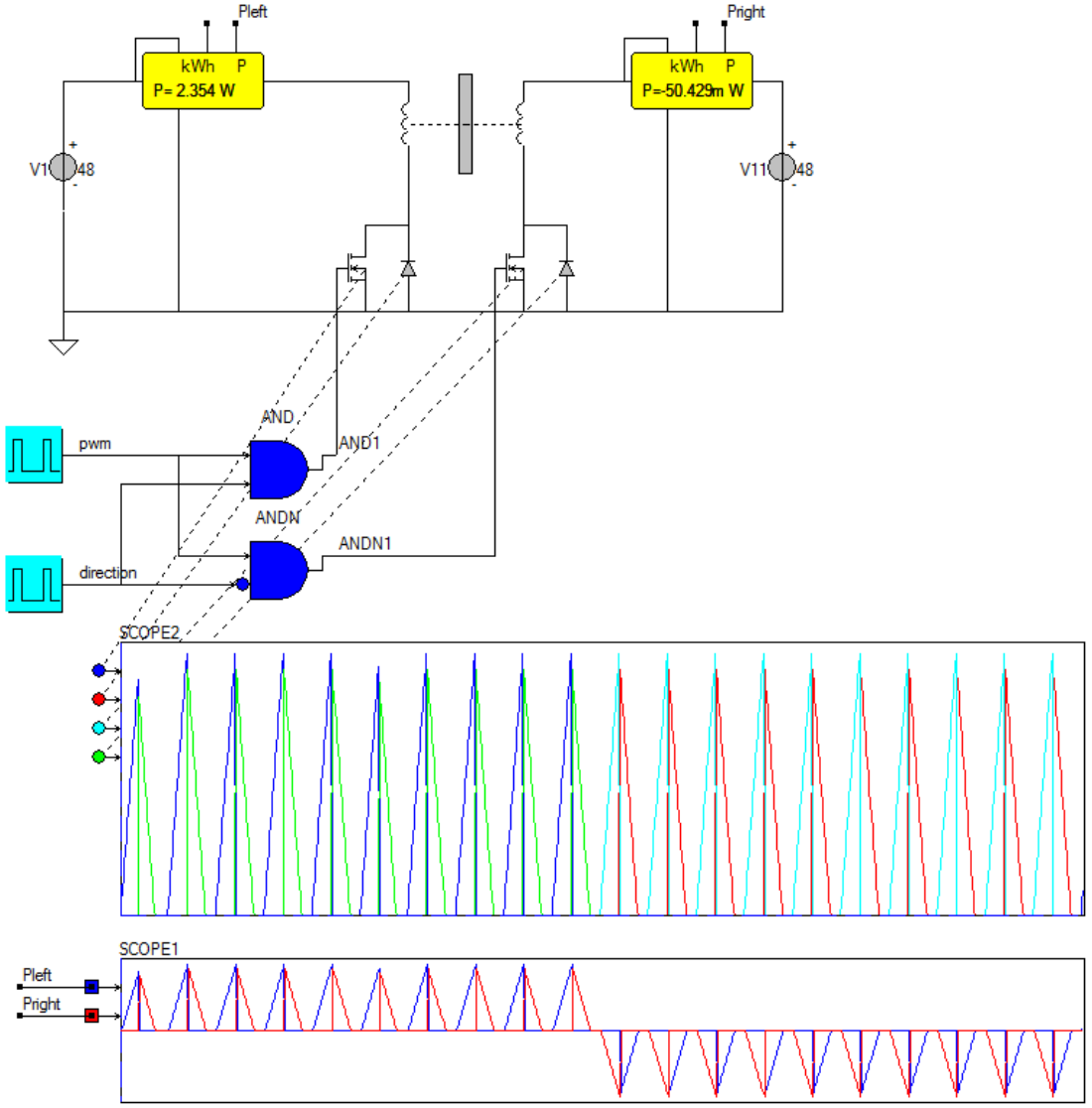

Ampere DC
-10
10
4.848
Volt DC
0
50
19.865
Ampere DC
-10
10
5.955
Volt DC
0
50
10.375
Temp
T
L1
100uH
L2
100uH
Ampere DC
-10
10
-3.016
SoC
SoC
SoC
SoC
L
ON
RX
TX
ICSP

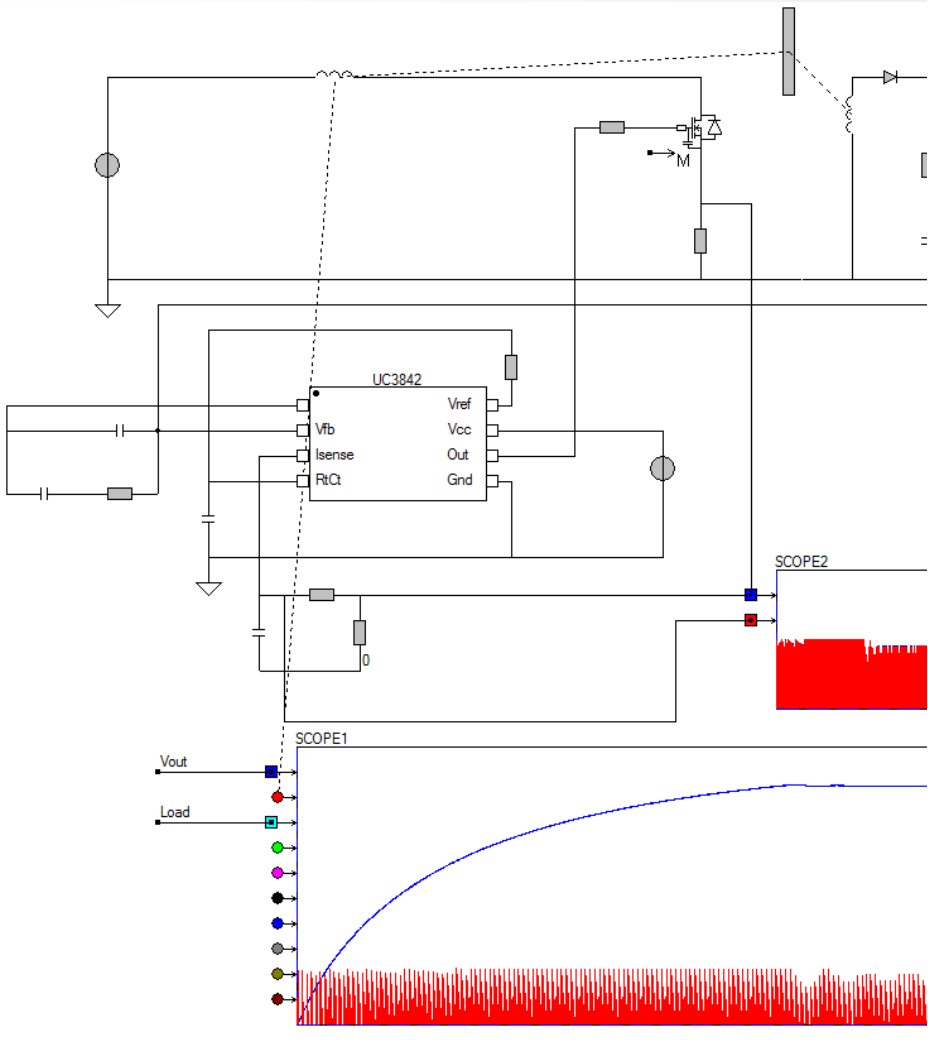

Ampere DC
-10
10
4.925
Volt DC
0
50
19.729
T
Temp
L1
100uH
USB-C 20volt
Ampere DC
-10
10
-483.004m
SoC
SoC
SoC
SoC
L
ON
RX
TX
ICSP

Bidirectional converter
Dual Active Bridge

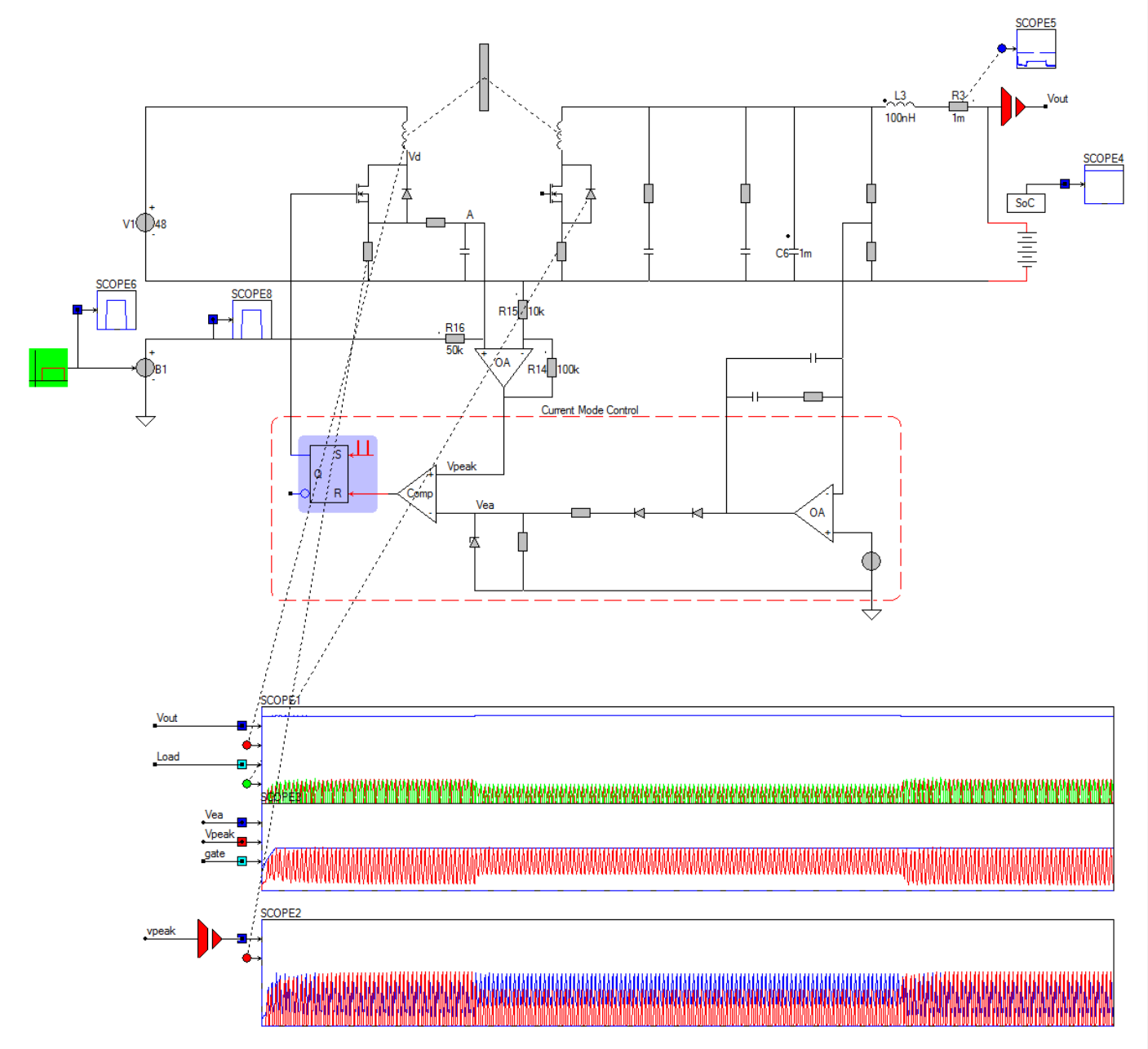


Bidirectional Flyback

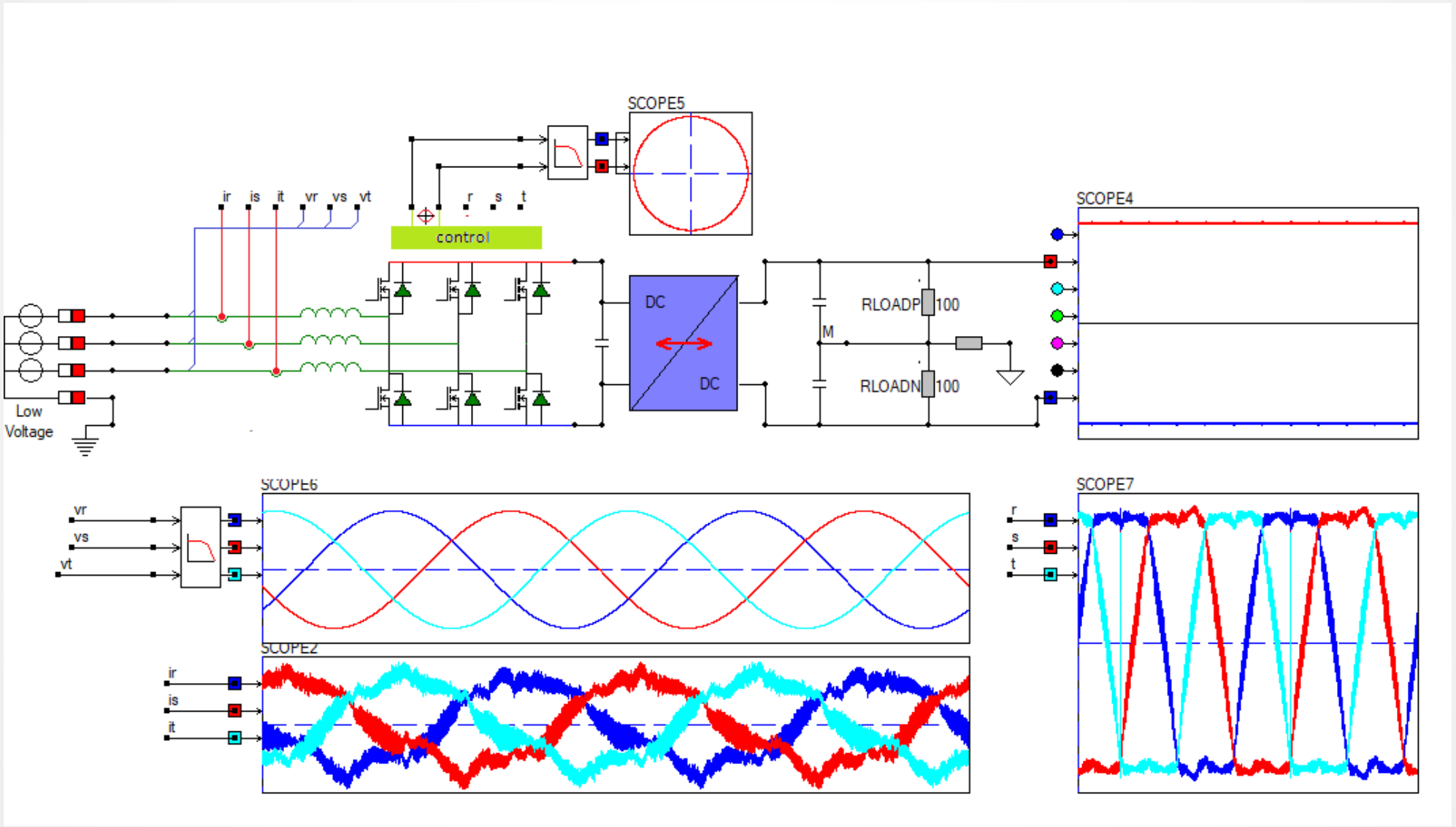




Flyback battery droop control



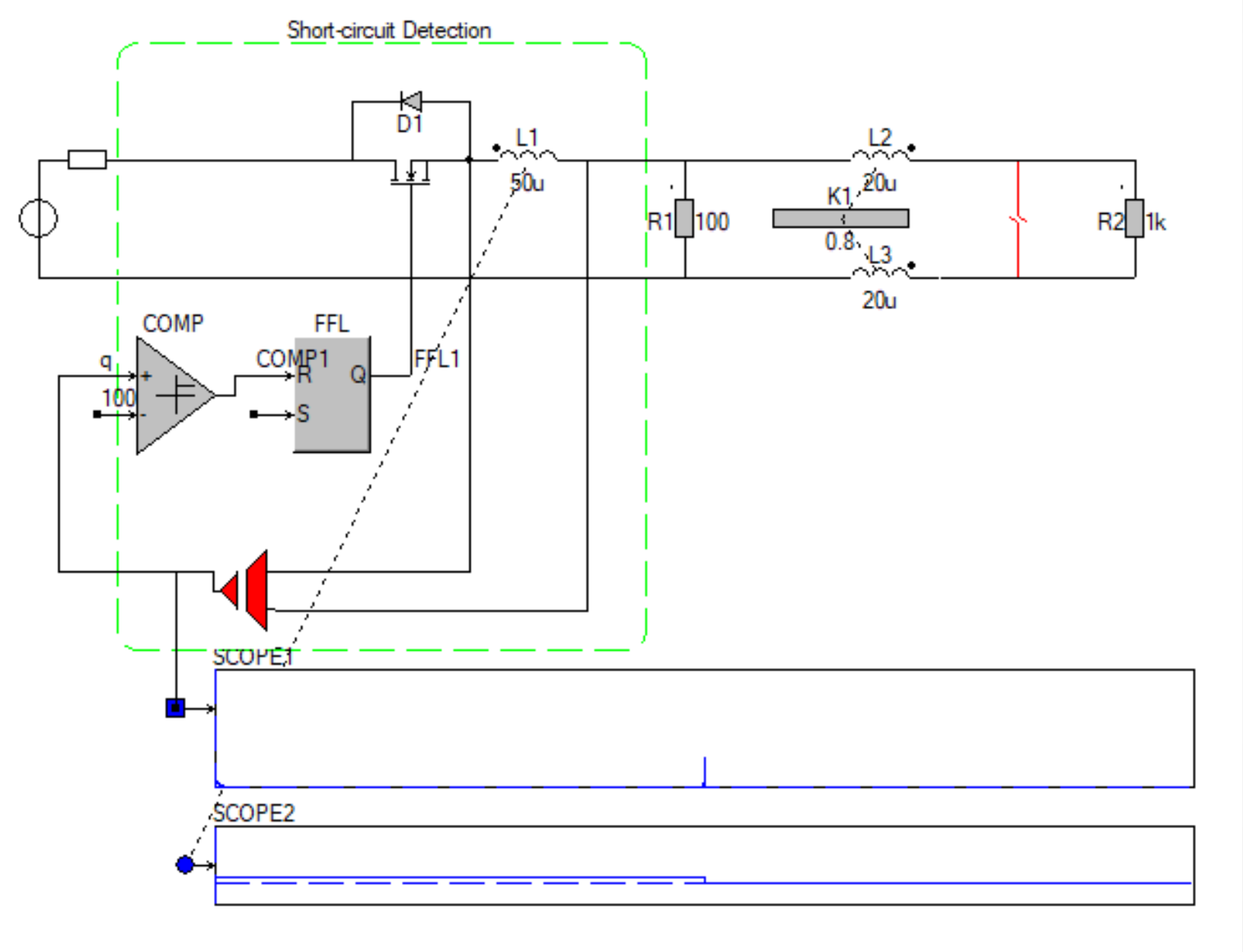
Interfacing AC and DC Bidirectional : Active Front End



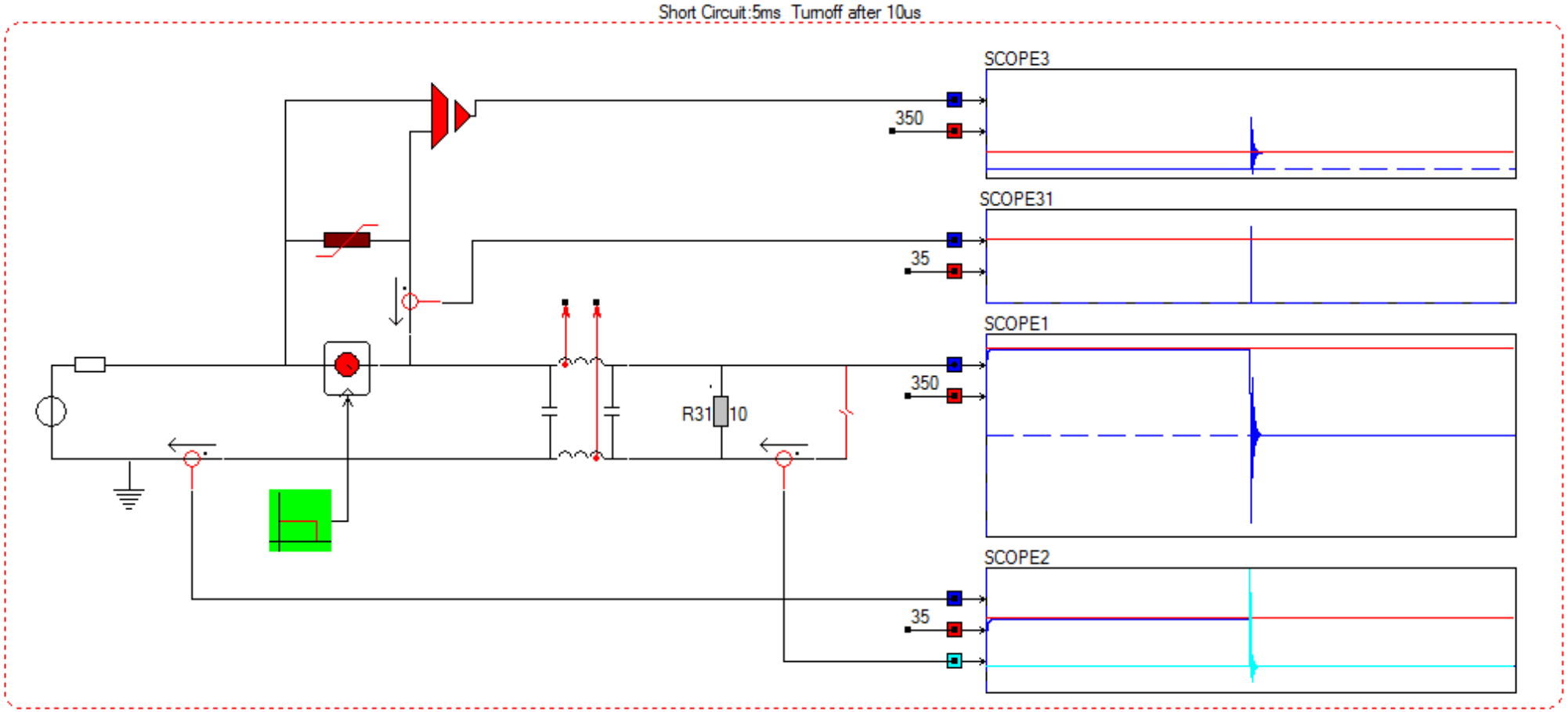
Part II Short Circuit Protection

- Maximum current
- RoCoC detection

Short circuit detection

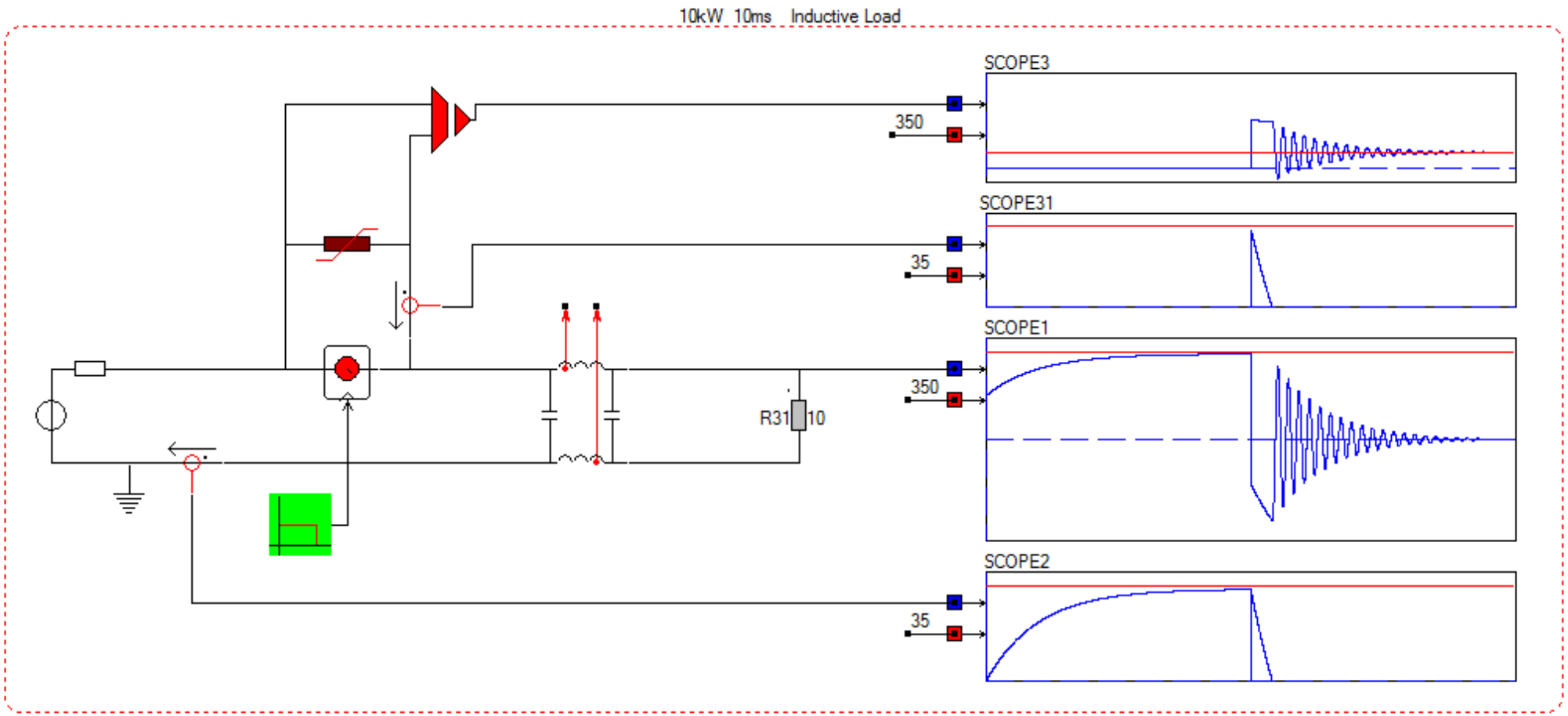


Turn-Off


Short Circuit:5ms Turnoff after 10us
SCOPE3
350
SCOPE31
35
SCOPE1
350
R31
10
SCOPE2
35

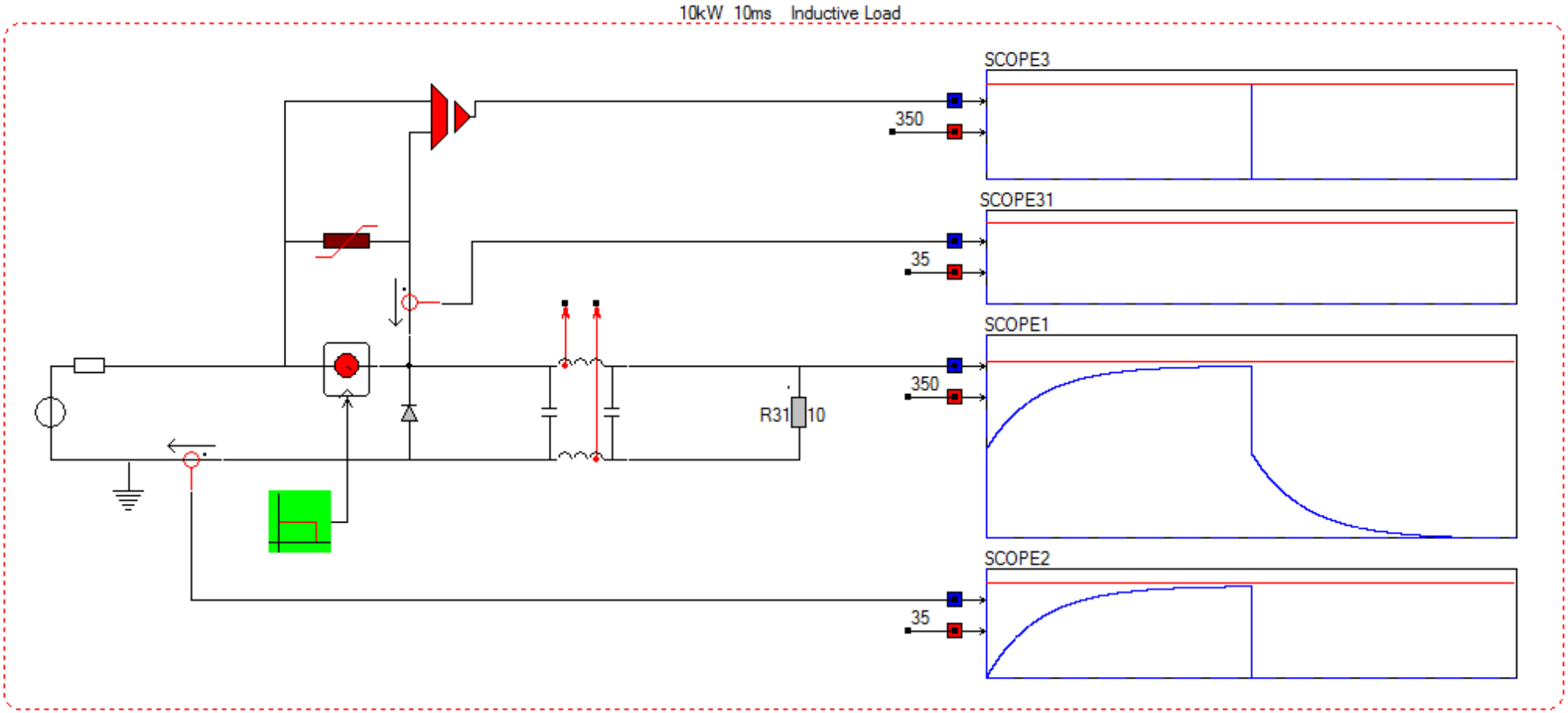
Turn-Off inductive Load

- Burn energy

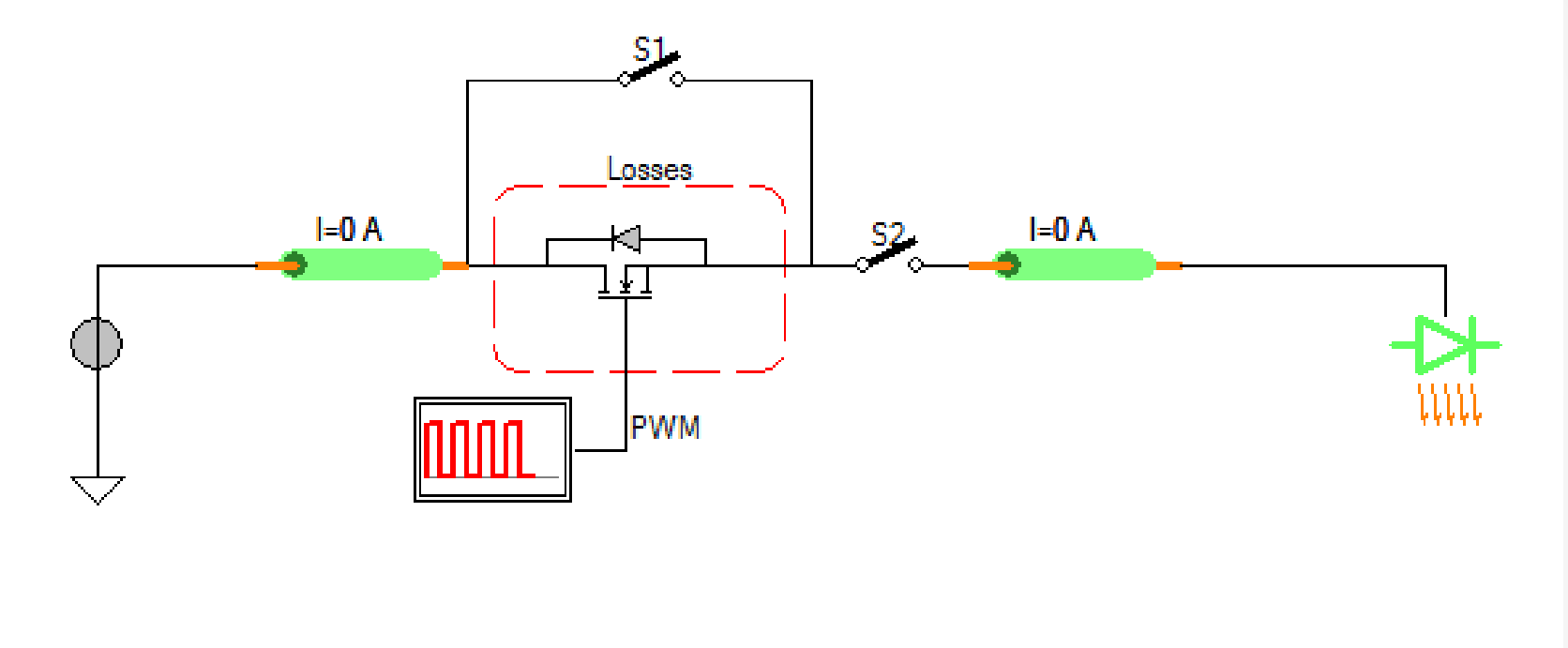


Turn-Off Inductive Load

- Freewheeling Energy



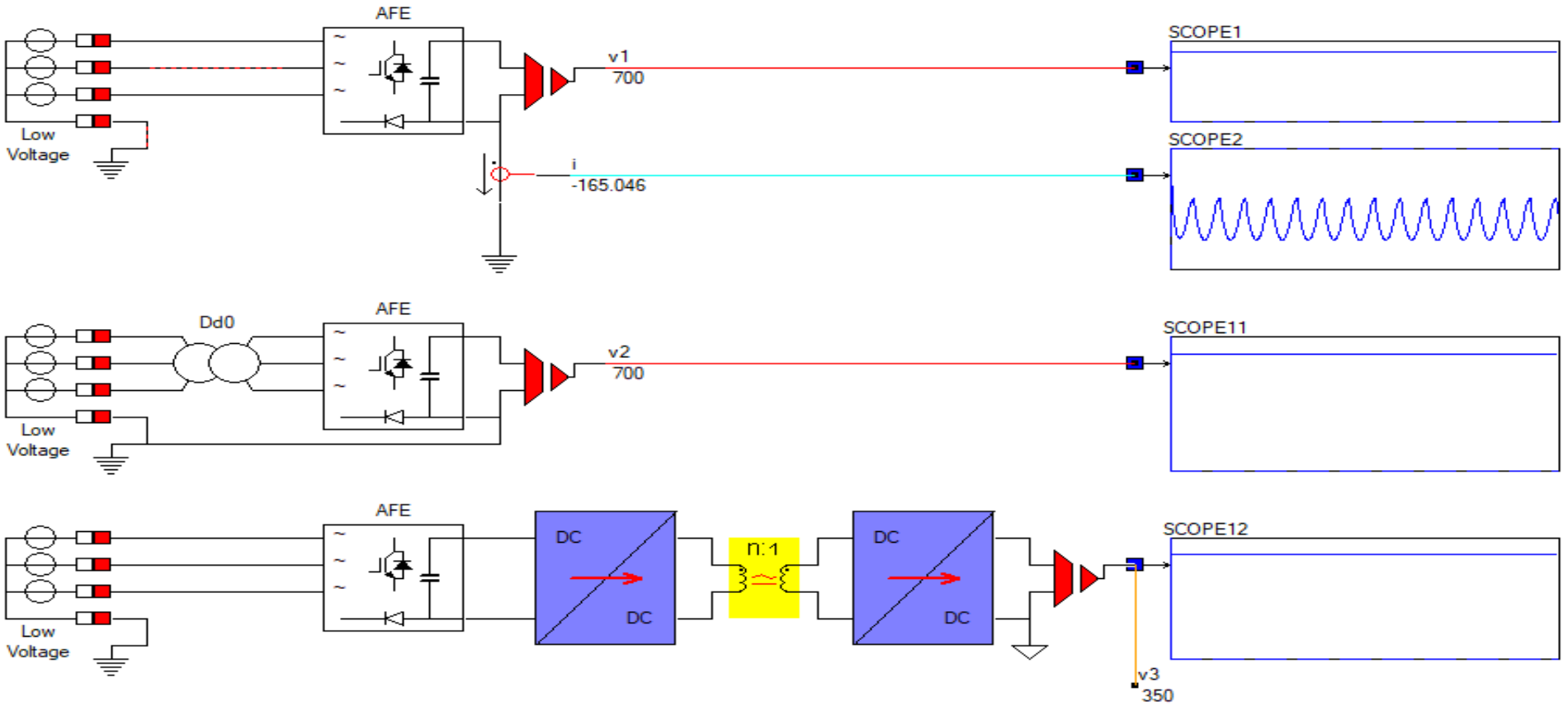
Hybrid Circuit Breaker



Part II Earth connection

- Midpoint connected to Earth
  - 0 volt level same as Earth
- Midpoint floating
  - Current monitoring at the 0 volt level
- Midpoint controlled floating
  - Allow small deviation of 0 volt level

Grounding

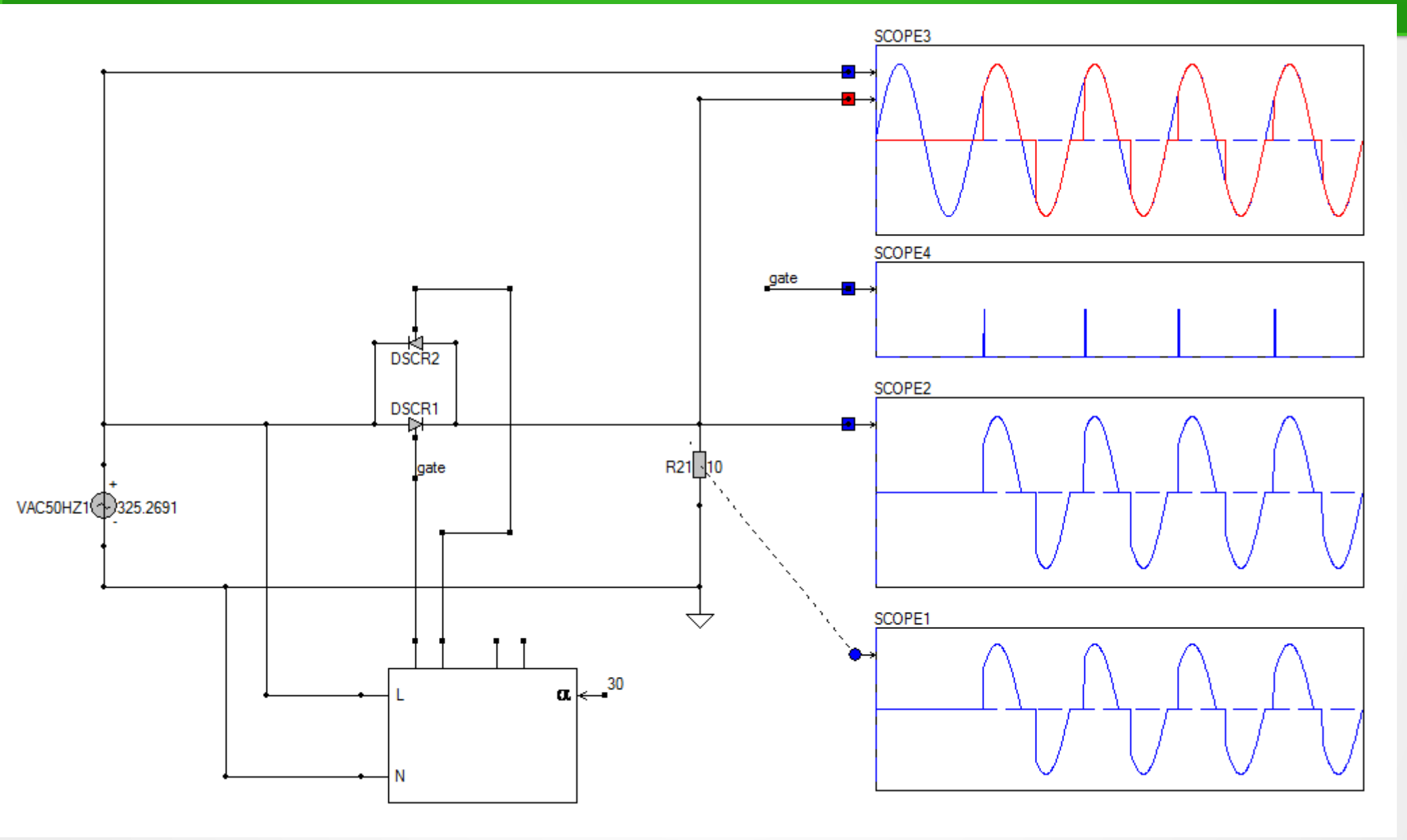

AFE
Low
Voltage
v1
700
i
-165.046
SCOPE1
SCOPE2
Dd0
AFE
Low
Voltage
v2
700
SCOPE11
AFE
Low
Voltage
DC
DC
n:1
DC
DC
SCOPE12
v3
350

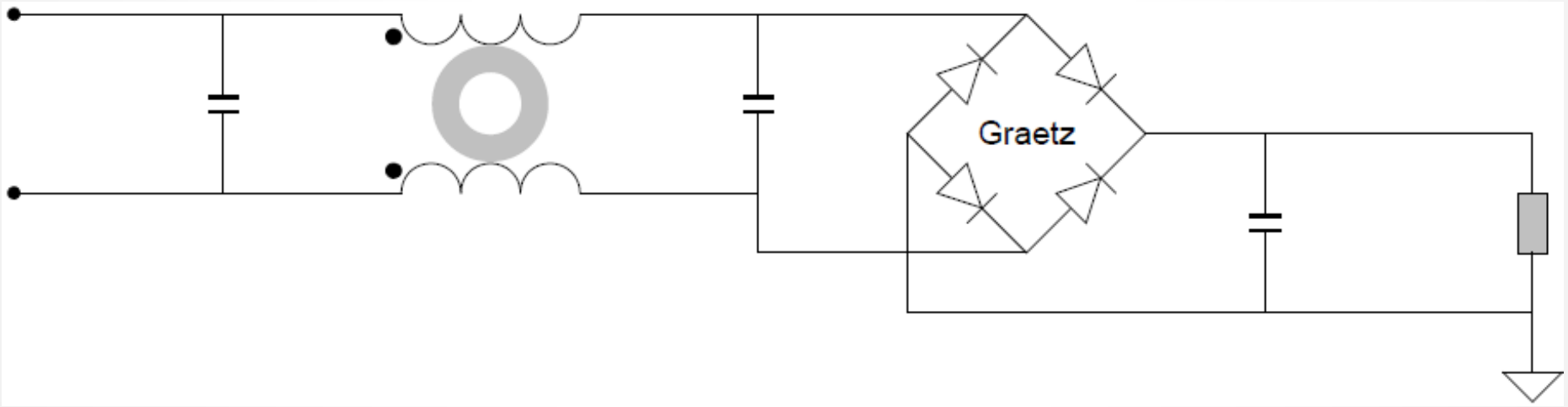
Part II Inrush

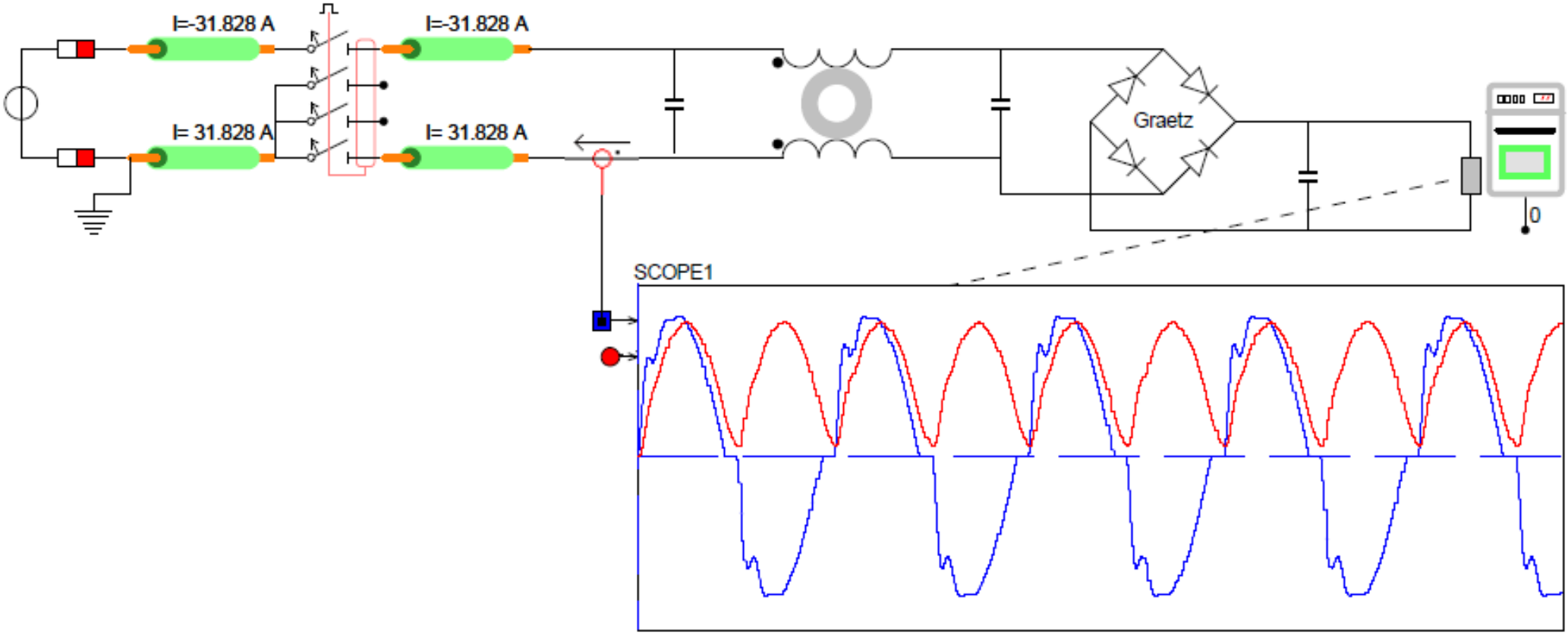
- Start up of appliances
  - Inrush current limiter
  - Increase of voltage
- Plug and Play?
  - USB-C

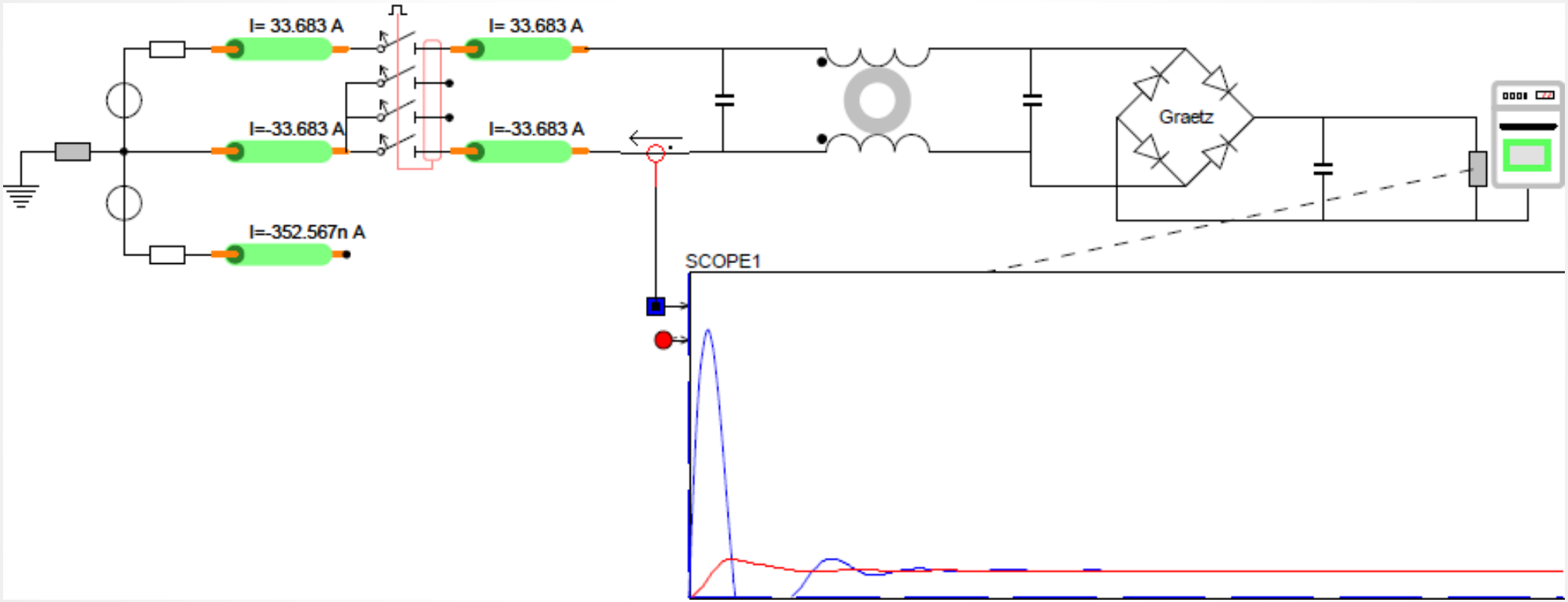
Inrush

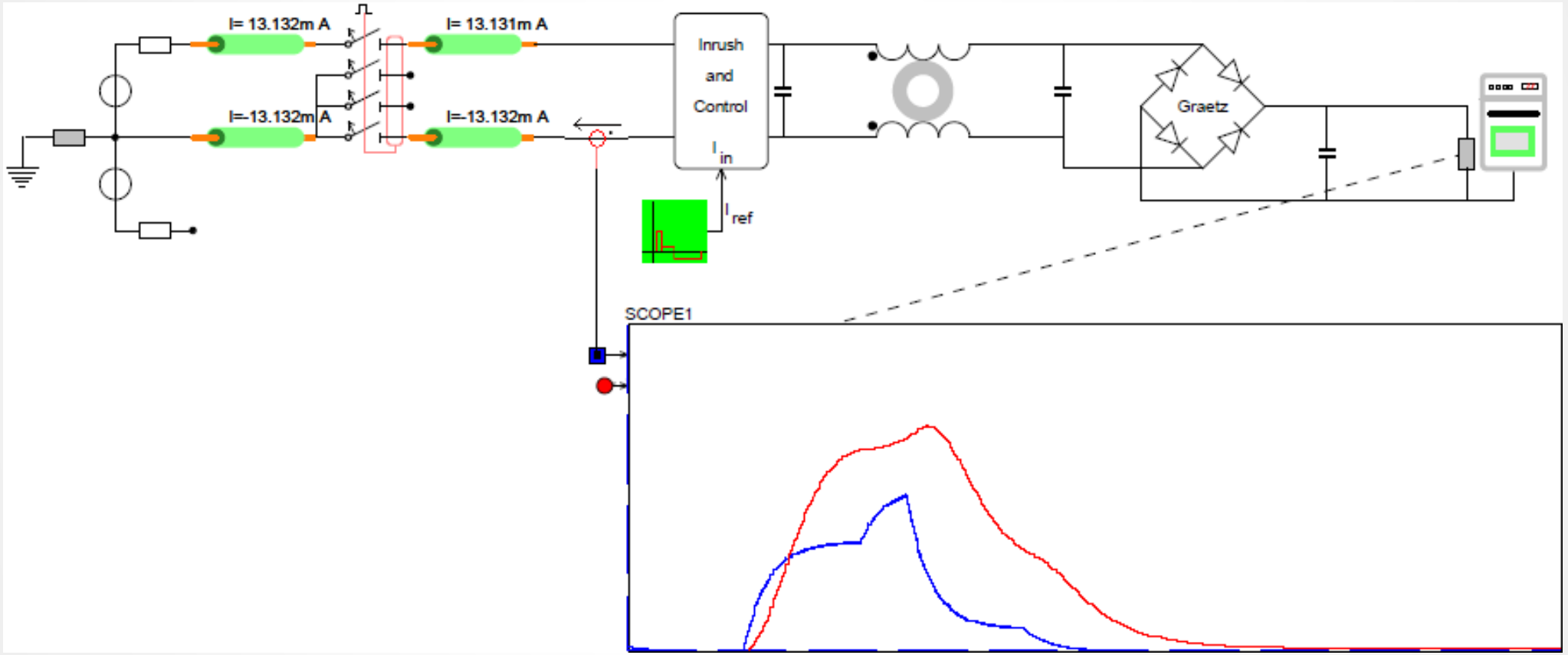
- Inrush protection
  - Passive
  - Active

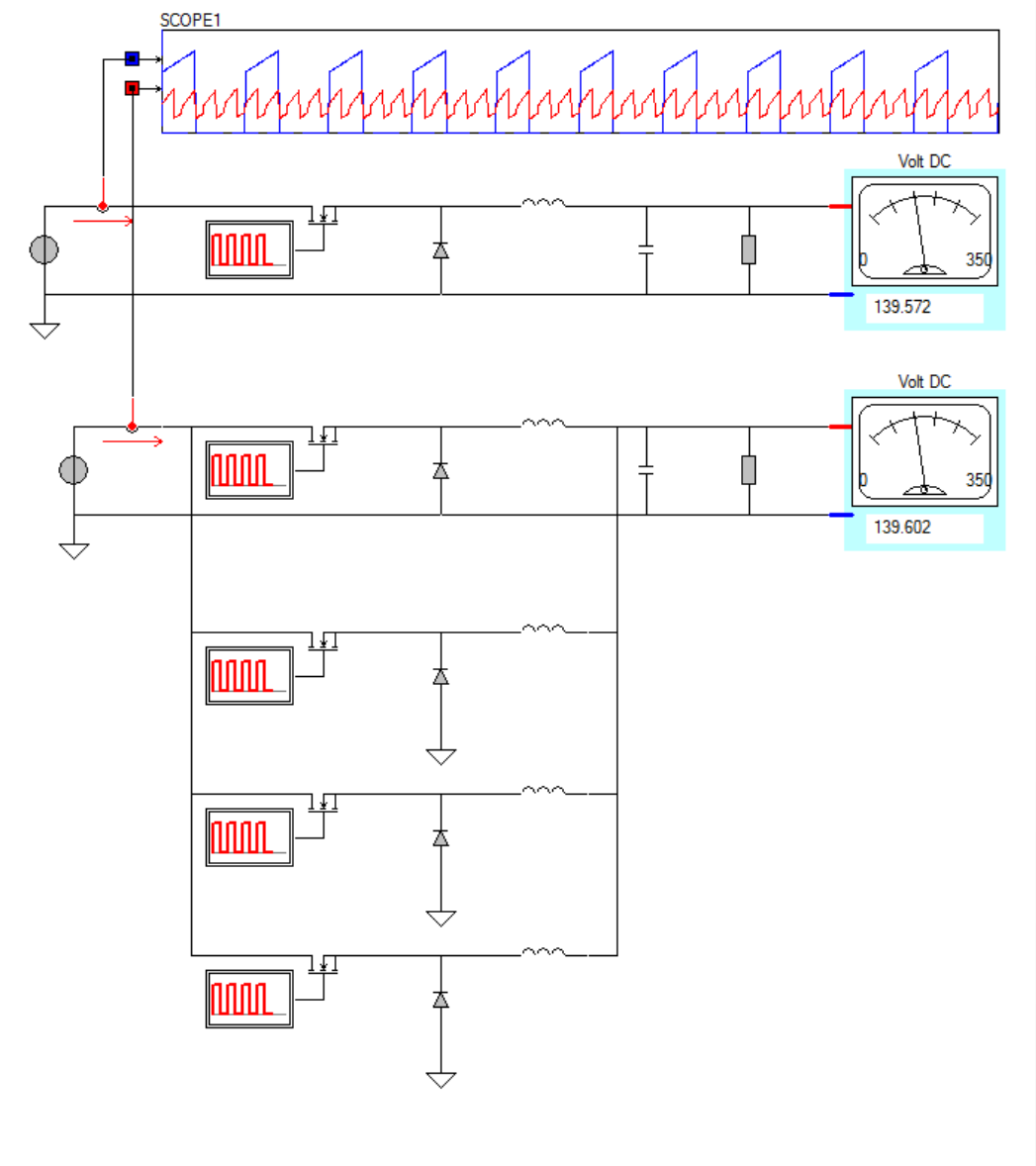

SCOPE3
SCOPE4
gate
SCOPE2
DSCR2
DSCR1
gate
R21
10
VAC50HZ1
325.2691
SCOPE1
L
α
30
N

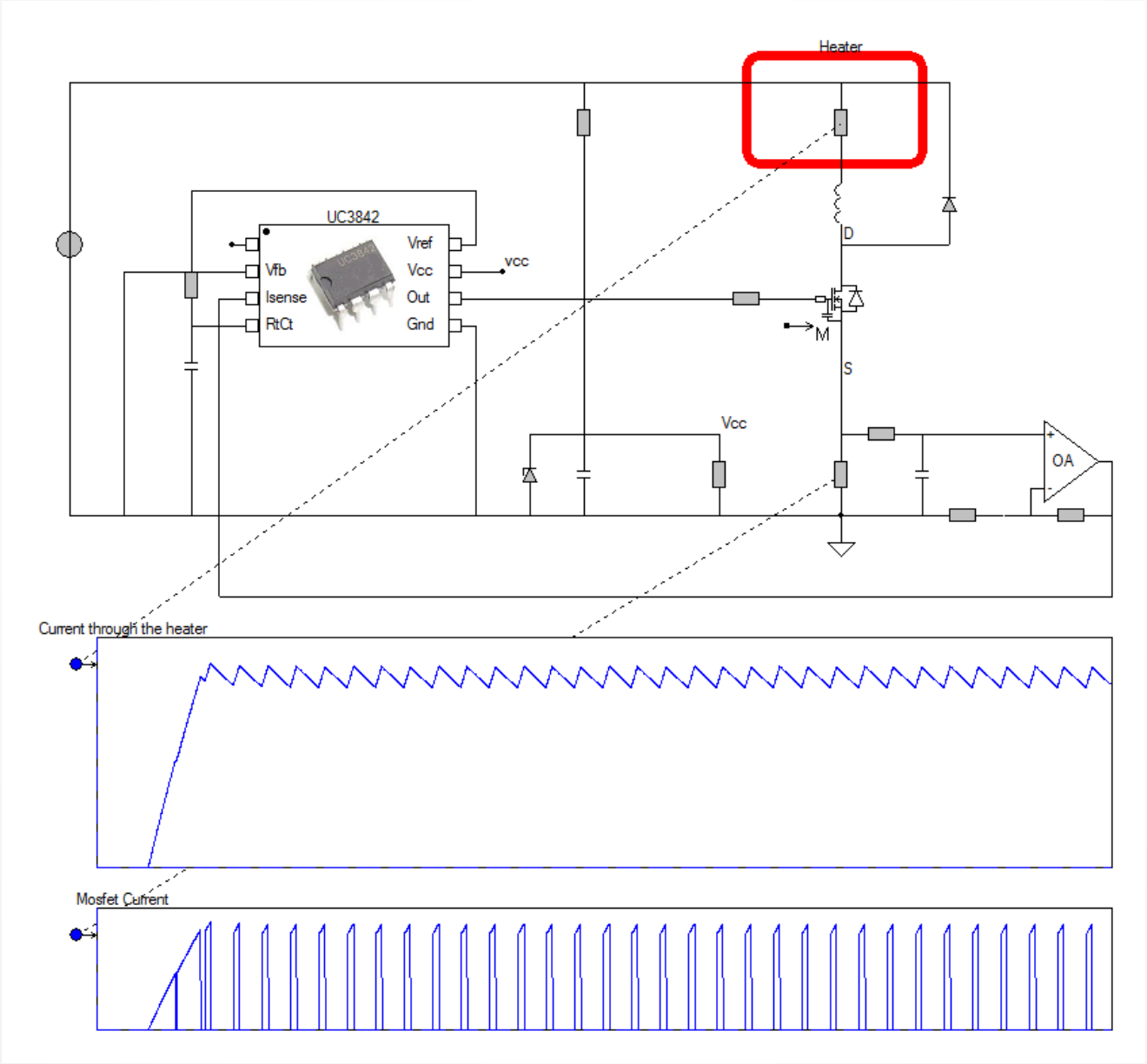

Graetz


I=-31.828 A
I=-31.828 A
I= 31.828 A
I= 31.828 A
Graetz
0
SCOPE1


I= 33.683 A
I= 33.683 A
I=-33.683 A
I=-33.683 A
I=-352.567n A
Graetz
SCOPE1


I= 13.132m A
I= 13.131m A
I=-13.132m A
I=-13.132m A
Inrush
and
Control
I in
I ref
Graetz
SCOPE1

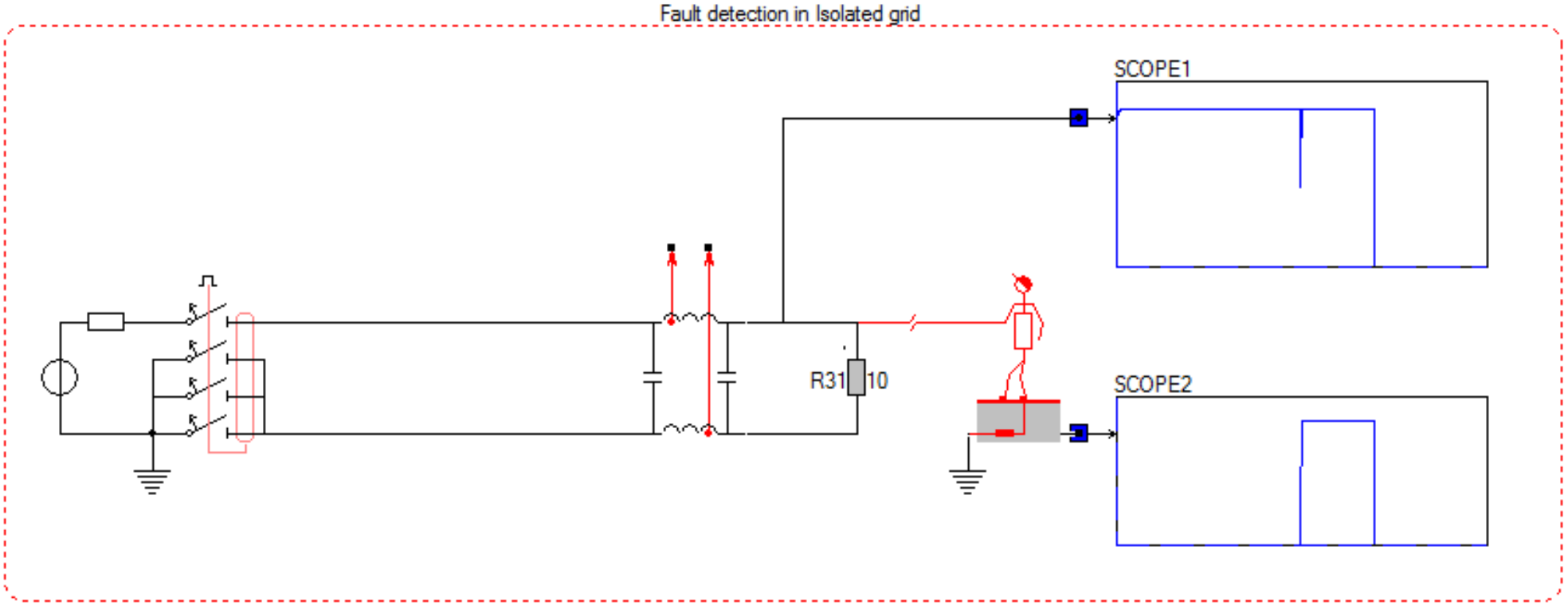

SCOPE1
Volt DC
0
350
139.572
Volt DC
0
350
139.602


Heater
UC3842
Vfb
Isense
RtCt
Vref
Vcc
Out
Gnd
vcc
D
M
S
Vcc
OA
Current through the heater
Mosfet Current

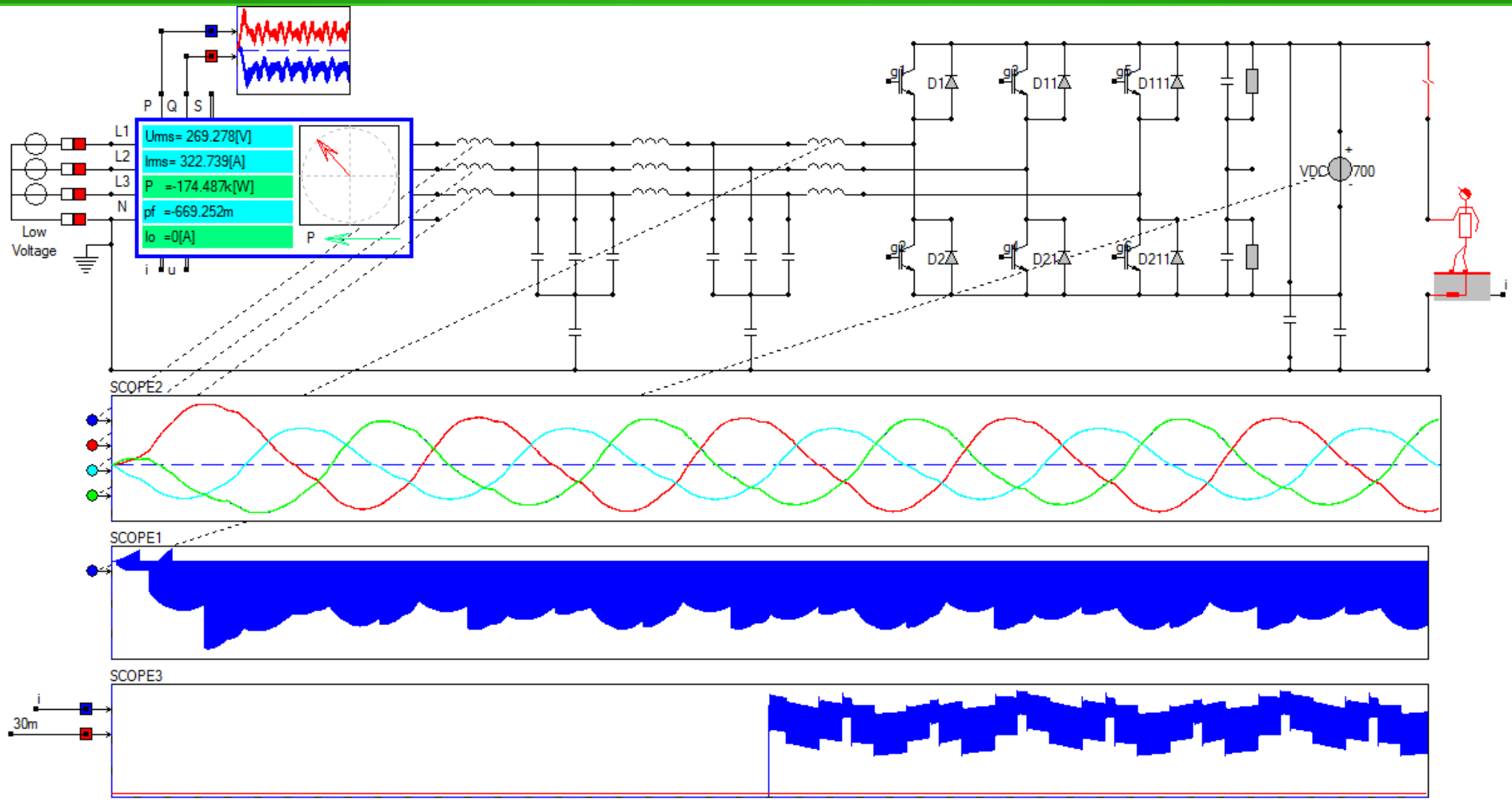
Part II Touch Safety

- Earth leakage detection in AC systems
  - Residual current detection
  - Leakage current monitoring (IT systems)
- Earth leakage detection in DC systems
  - Residual current detection
  - Leakage current detection (IT systems)
- Earth leakage detection in Vintage AC outlet

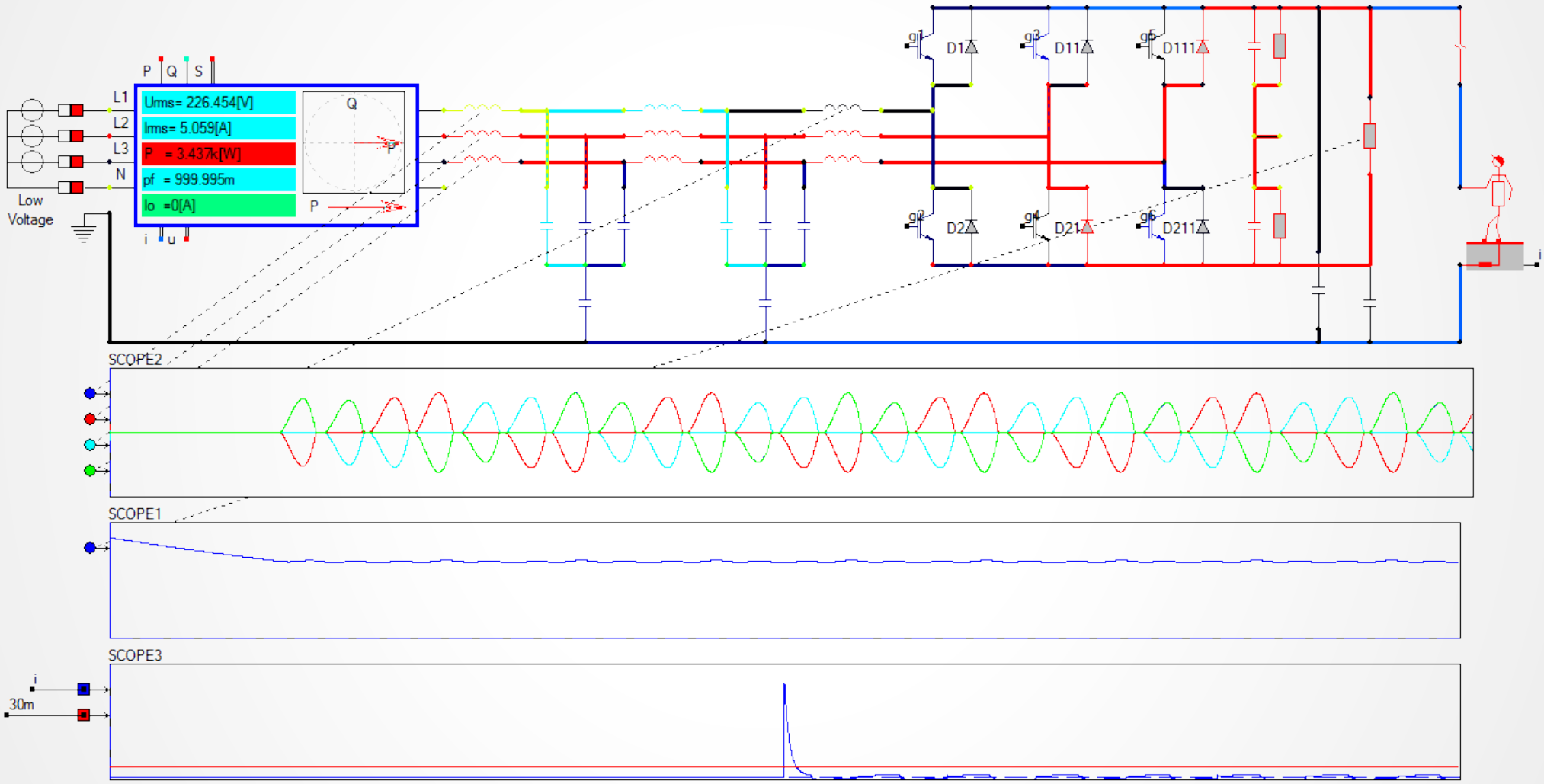
Earth leakage



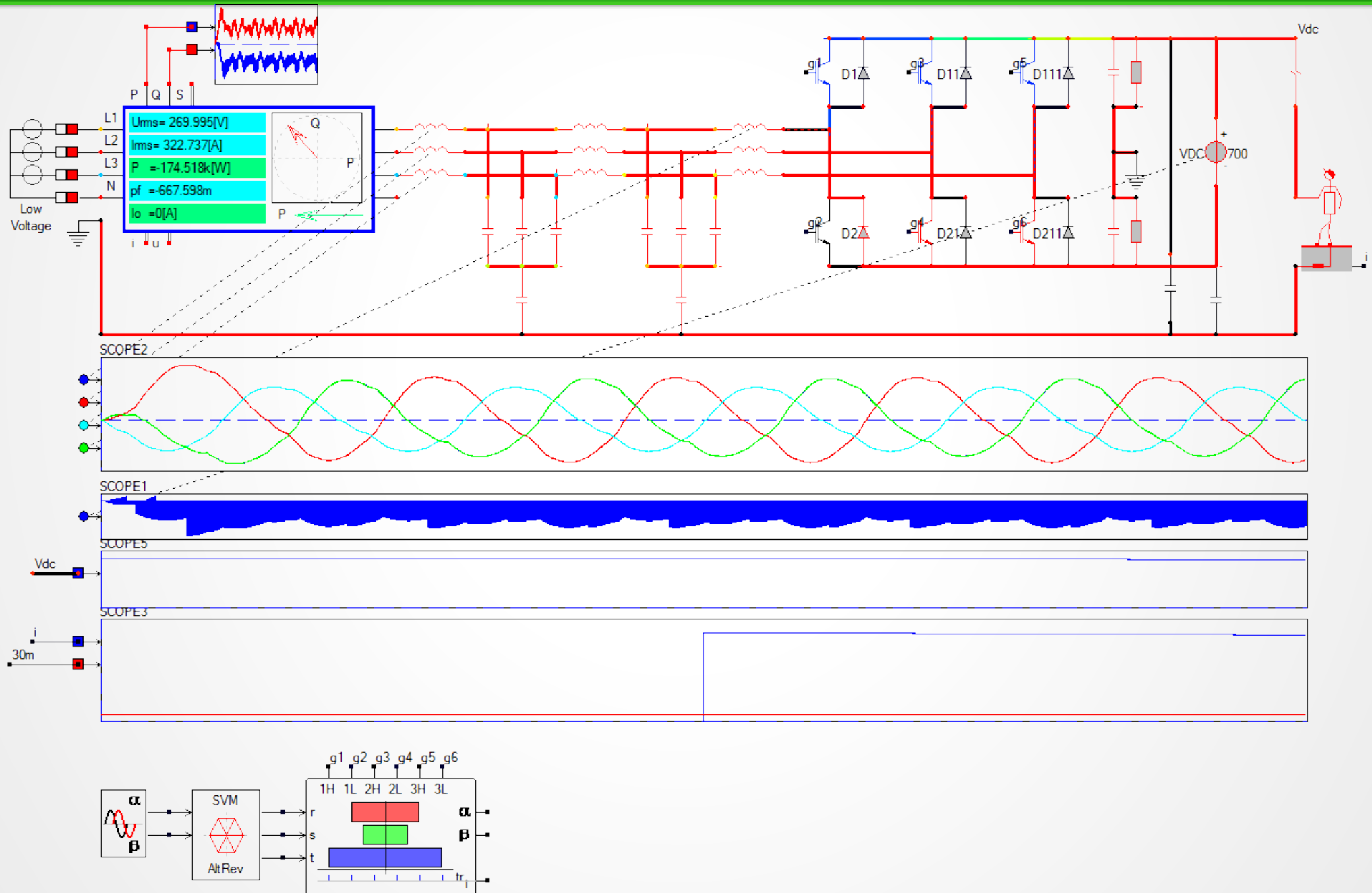
AC TT Grid


P
Q
S
L1
L2
L3
N
Low
Voltage
Urms= 269.278[V]
Irms= 322.739[A]
P =-174.487k[W]
pf =-669.252m
Io =0[A]
P
i
u
D1
D11
D111
D2
D21
D211
VDC
700
SCOPE2
SCOPE1
SCOPE3
i
30m
g1 g2 g3 g4 g5 g6
1H 1L 2H 2L 3H 3L
SVM
AltRev
r
s
t
α
β
fr

AC TI Grid DC grid Isolated



AC TI Grid DC Grid Ground M



Part II Islanding

- AC: 50Hz Synchronization is required!
- DC: No Synchronization required
- DC: Local Earth protection is required

Conclusion

- Is protection easier in DC compared to AC?
  - Short circuit detection or RoCoC?
  - Earth Leakage, RCD or Current monitoring
  - Earth leakage detection on longer cables
- AC and DC Different?
  - Inrush
  - Turn-Off inductive load
  - Earth leakage via cable leakage capacitance

Questions?

www.caspoc.com/news/workshops/dctrees