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Fast Hardware Protection for a Series-Series Compensated Inductive Power Transfer System for Electric Vehicles

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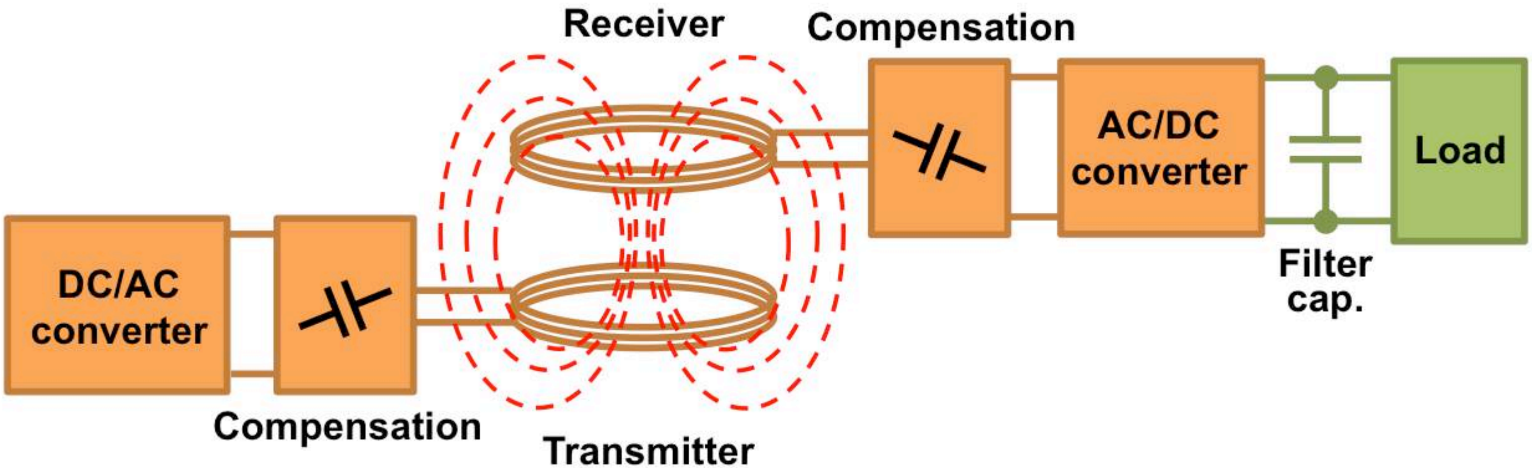
Acknowledgments:

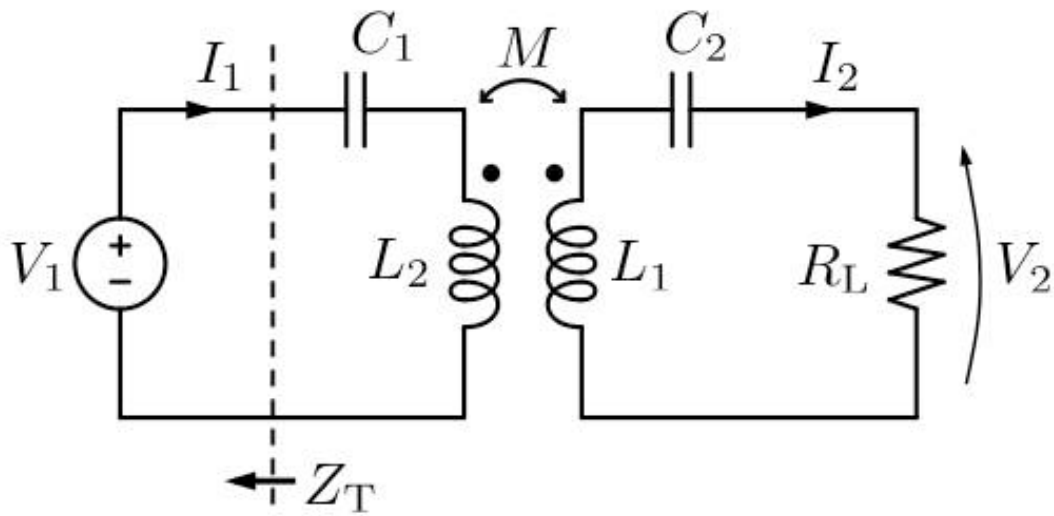
Outline

- IPT basics
- Adopted simplified model
- The need for fast protection
- Adopted solution
- Simulation
- Implementation and testing

Basic IPT system for EV

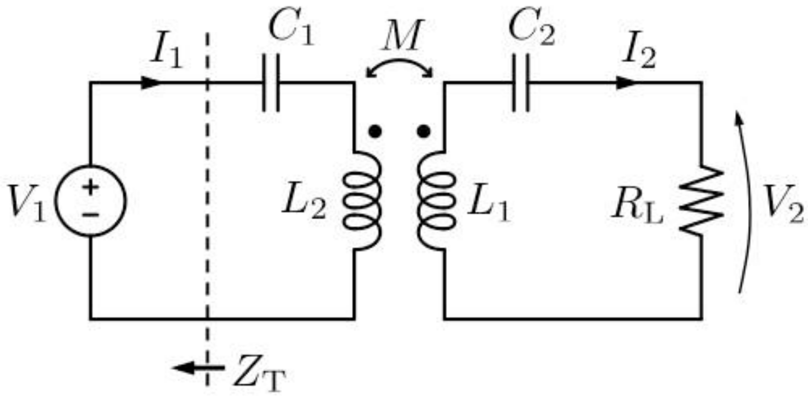


Simplified circuit model (FHA)



$$\omega_0 = \frac{1}{\sqrt{L_1 C_1}} = \frac{1}{\sqrt{L_2 C_2}}$$

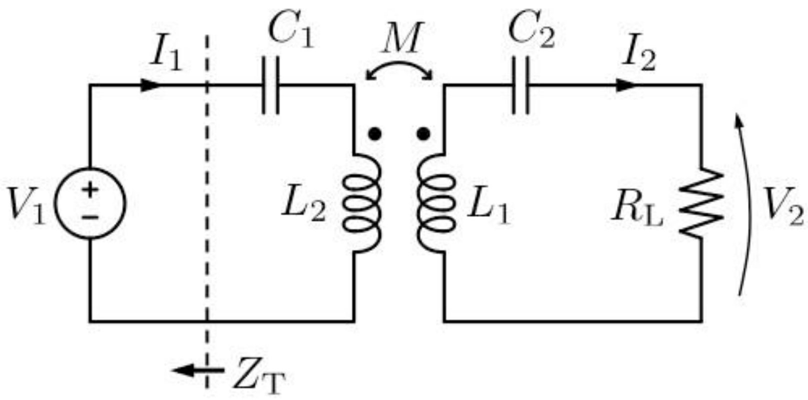
Series-series compensation



$$\overline{Z}_{\mathrm{T}} = \frac{\overline{V}_1}{\overline{I}_1} = j\left(\omega L_1 - \frac{1}{\omega C_1}\right) + \frac{\omega^2 M^2}{R_{\mathrm{L}} + j\left(\omega L_2 - \frac{1}{\omega C_2}\right)}$$

$$\omega = \omega_0$$

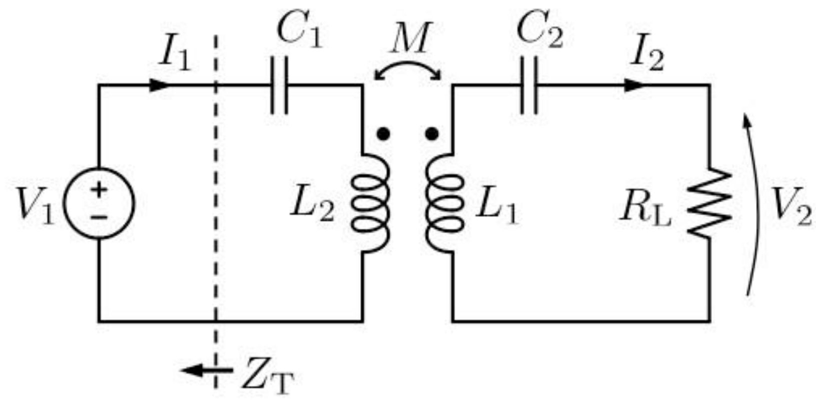
$$Z_{\mathrm{T}} = \frac{\omega^2 M^2}{R_{\mathrm{L}}}$$



$$\omega = \omega_0$$

$$I_1 = \frac{R_L}{\omega^2 M^2} V_1$$

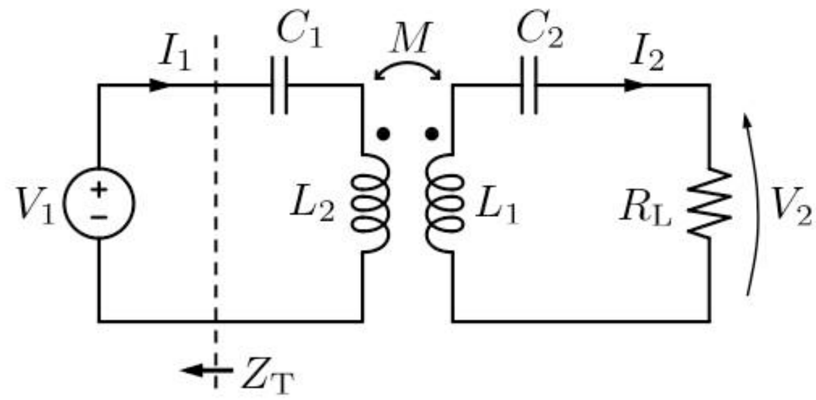
$$V_{oc} = \omega M I_1$$



$$I_1 = \frac{R_L}{\omega^2 M^2} V_1$$

$$V_{oc} = \omega M I_1$$

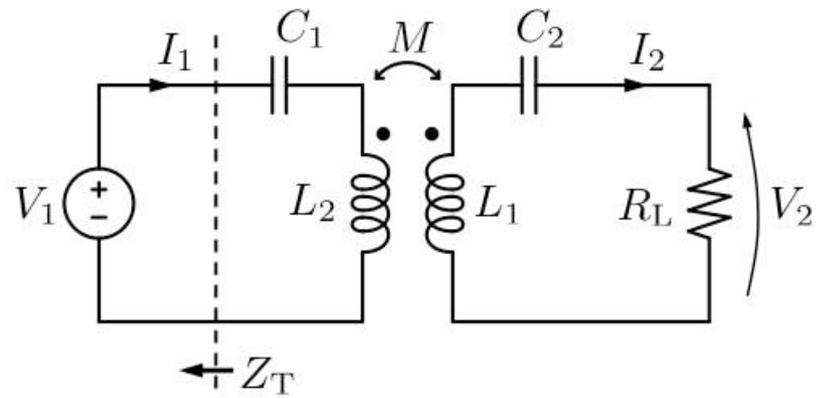
$$I_2 = \frac{V_{oc}}{R_L}$$



$$I_1 = \frac{R_L}{\omega^2 M^2} V_1$$

$$V_{oc} = \omega M I_1$$

$$I_2 = \frac{V_{oc}}{R_L} = \frac{\omega_0 M}{R_L} I_1$$



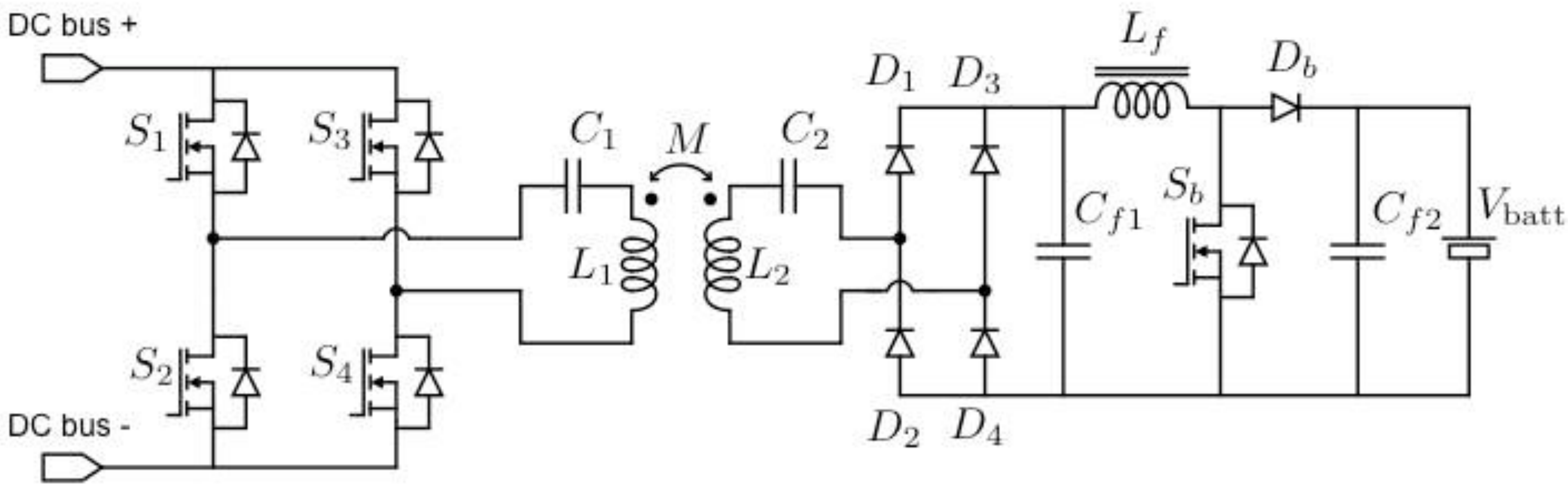
$$I_1 = \frac{R_{\mathrm{L}}}{\omega^2 M^2} V_1$$

$$V_{\mathrm{oc}} = \omega M I_1$$

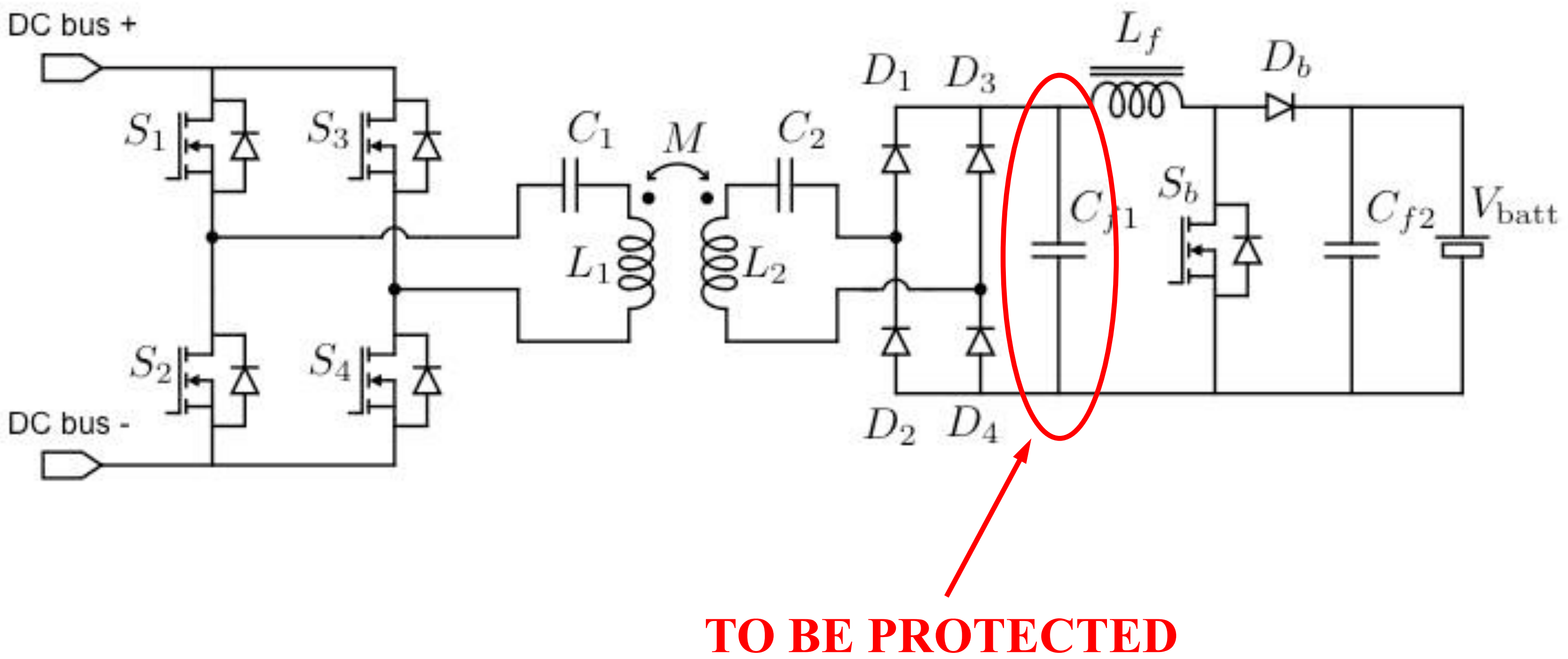
$$I_2 = \frac{V_{\mathrm{oc}}}{R_{\mathrm{L}}} = \frac{\omega_0 M}{R_{\mathrm{L}}} I_1$$

$$I_2 = \frac{V_1}{\omega_0 M}$$

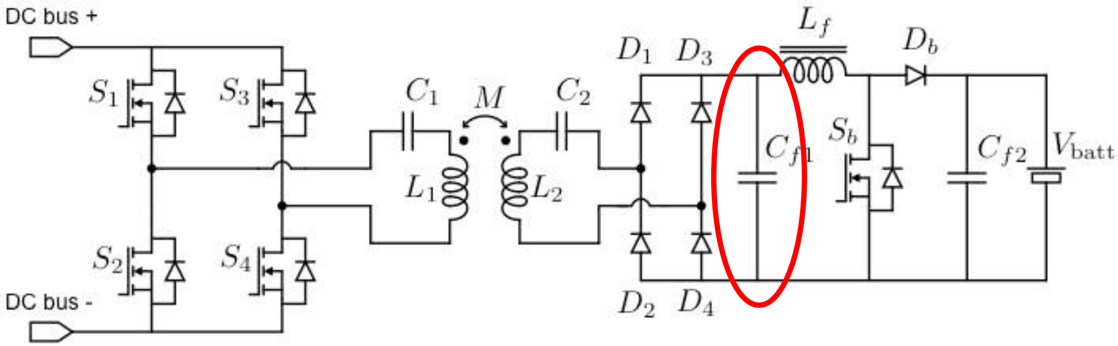
Studied architecture

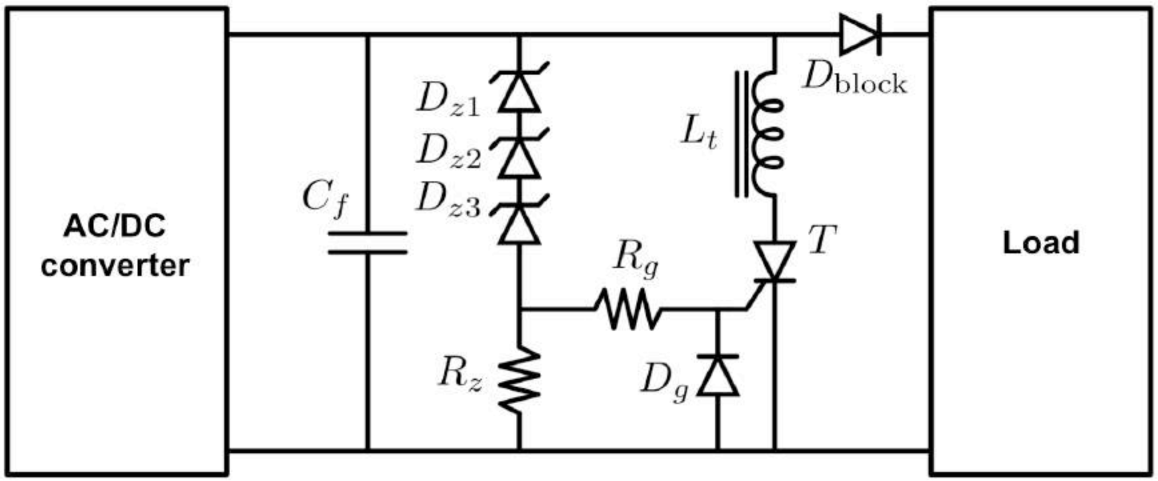


Studied architecture

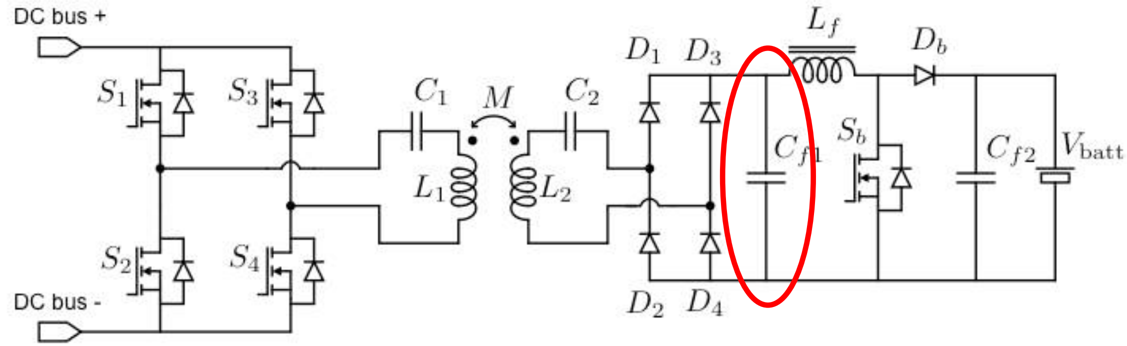


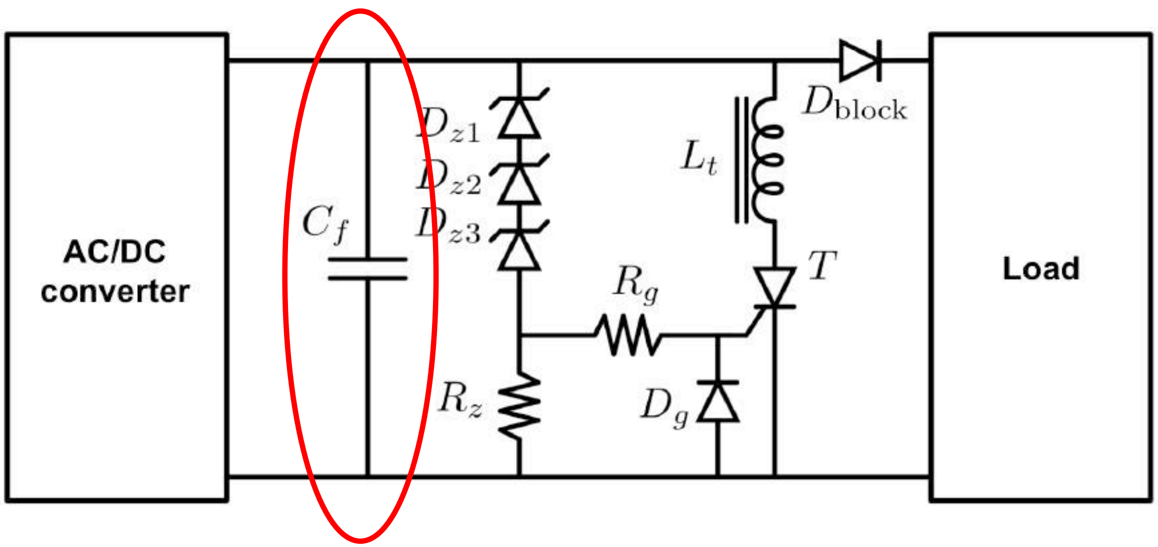
Protection circuit



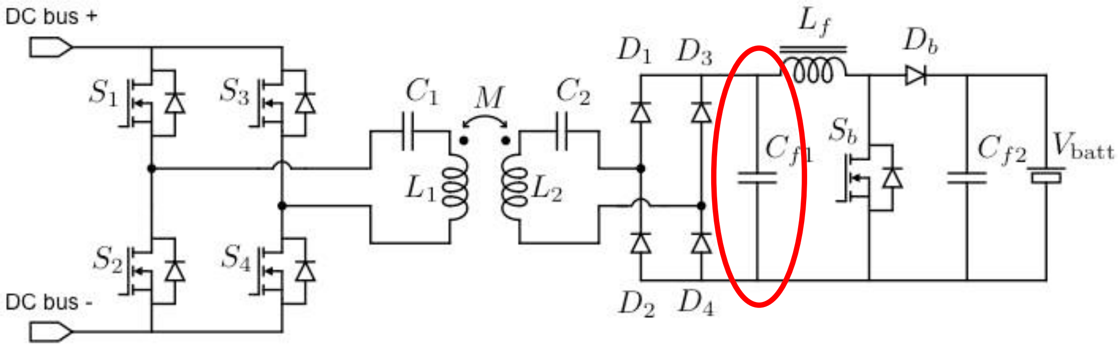


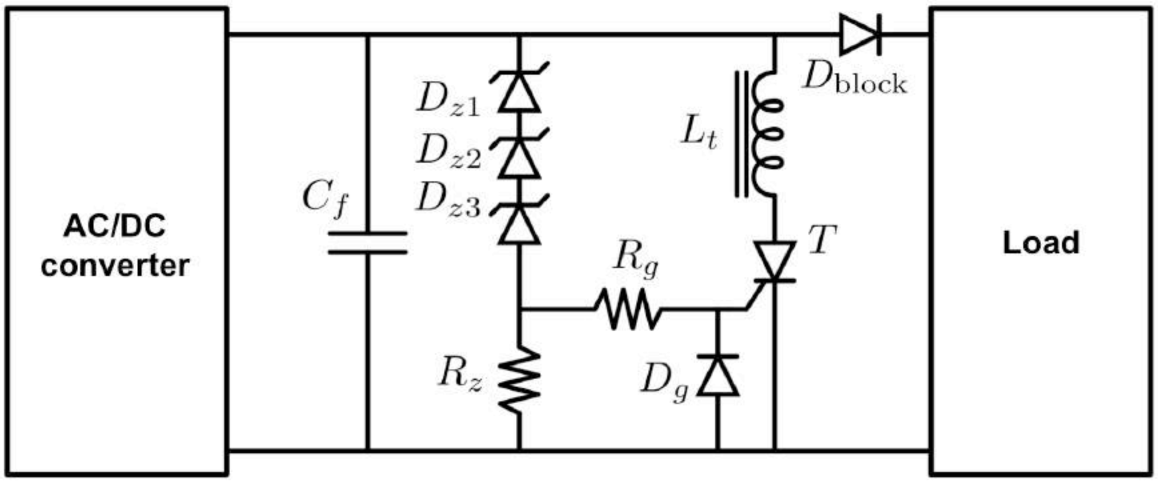
Protection circuit



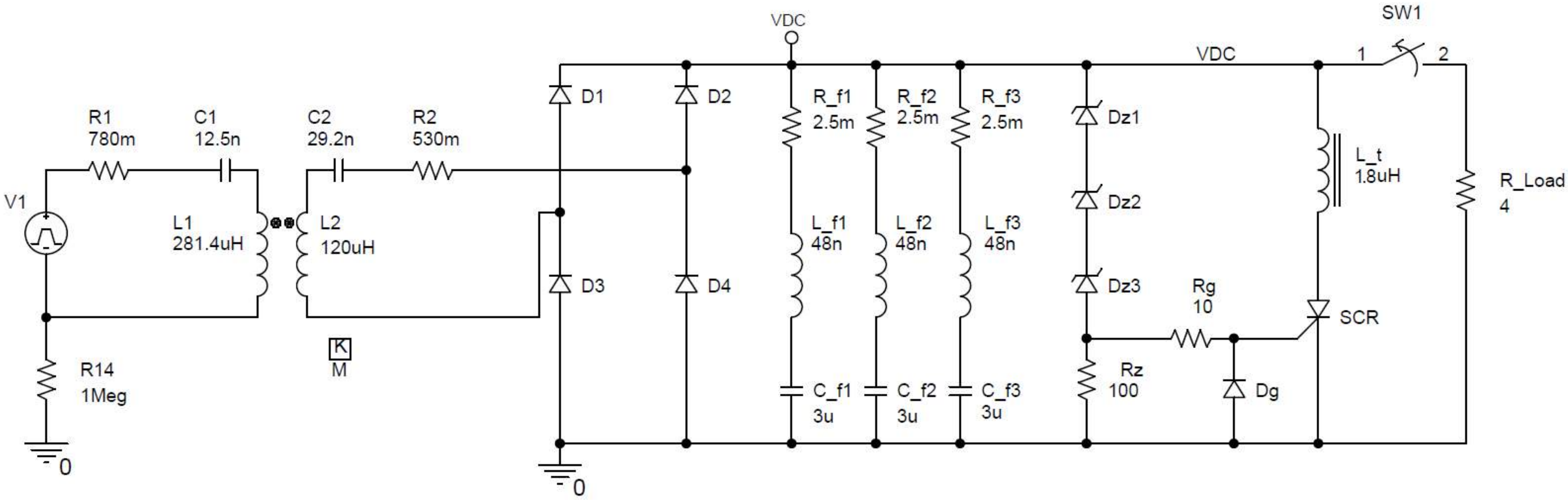


Protection circuit



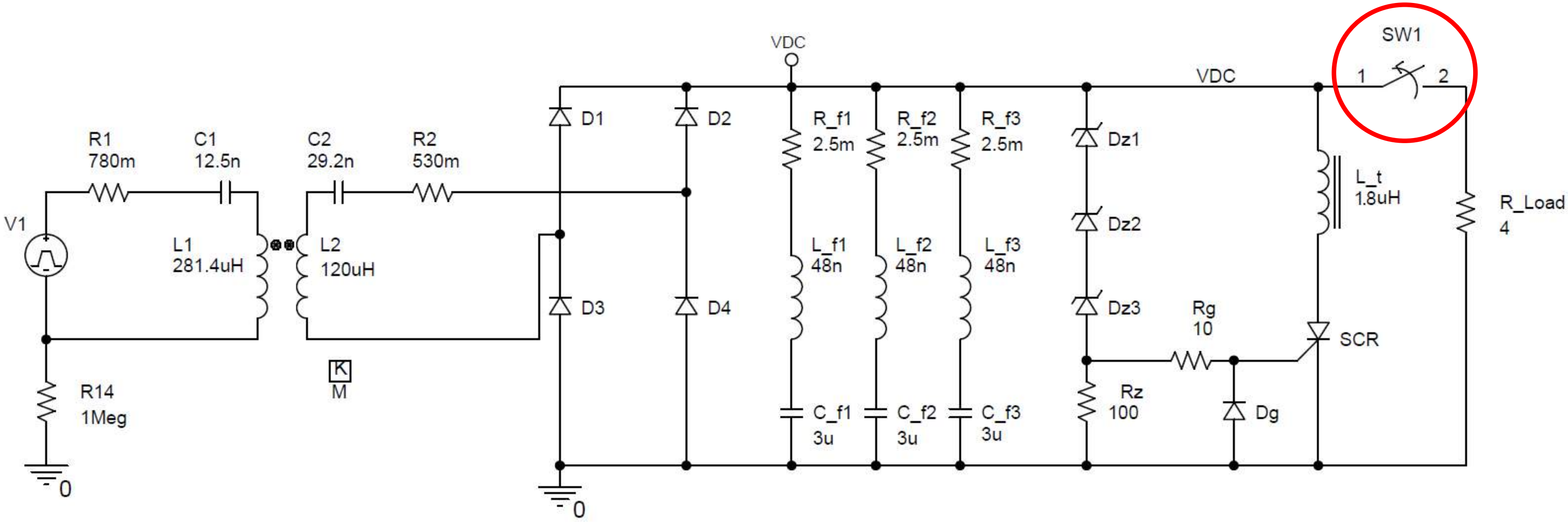


Simulation scheme

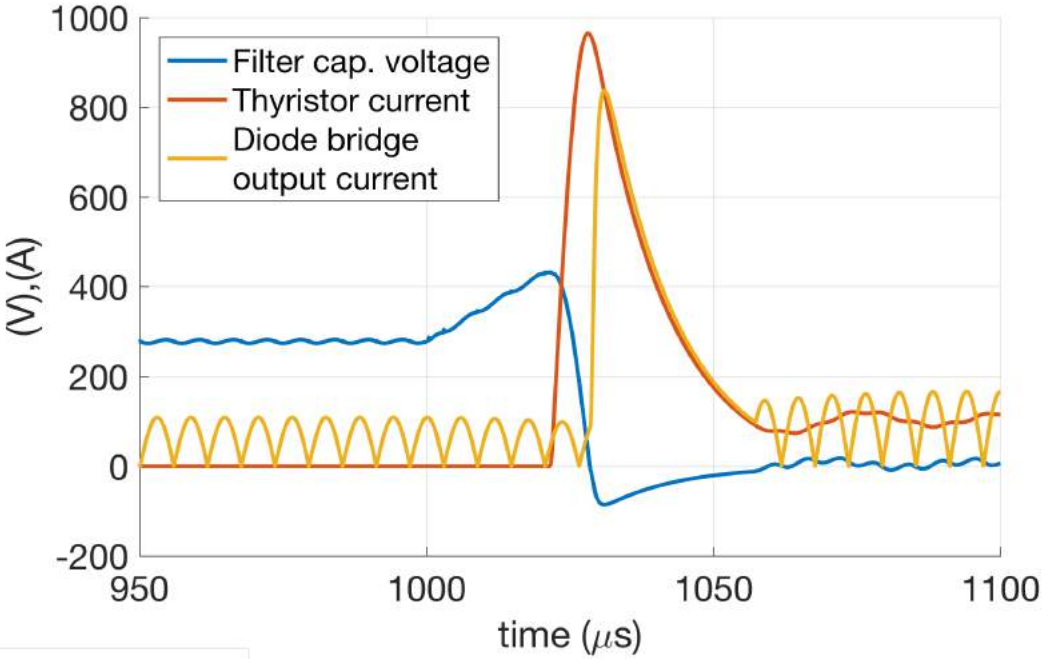


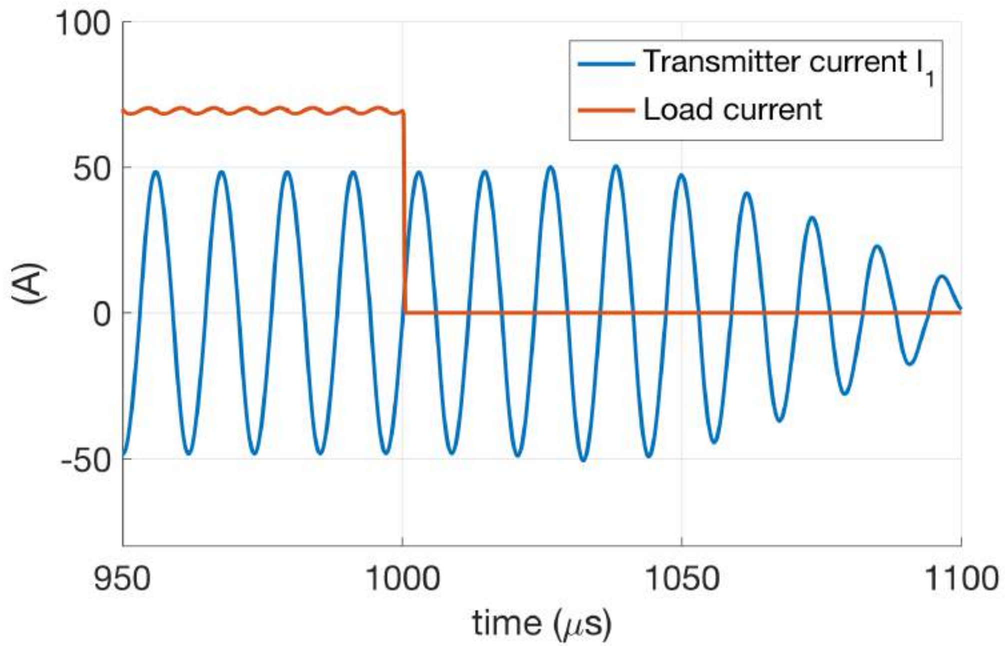
Simulation scheme

LOAD DISCONNECTION

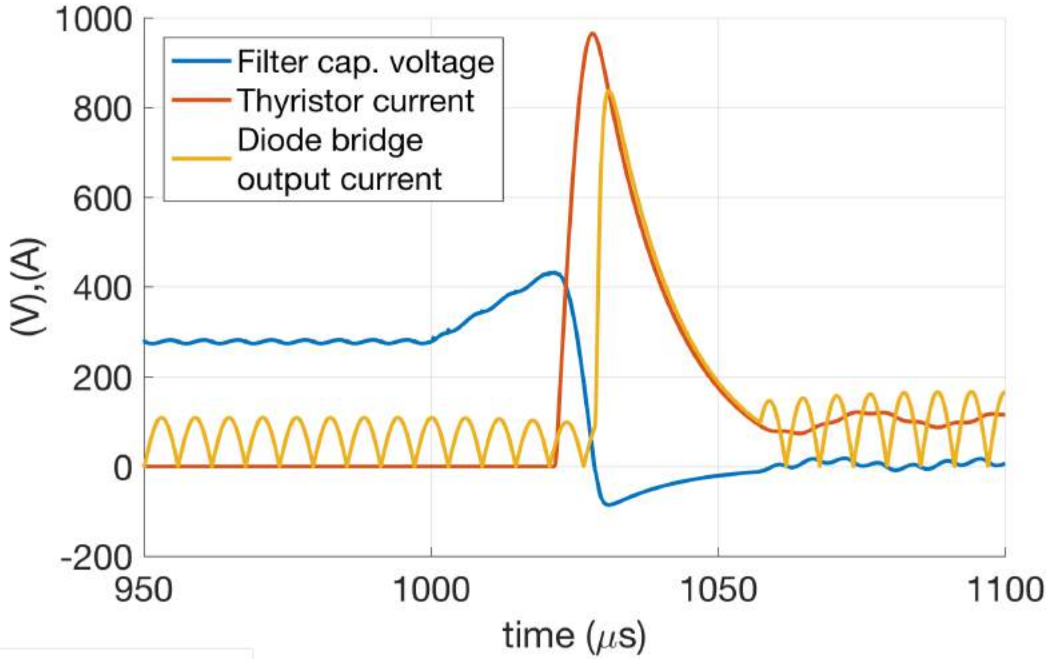


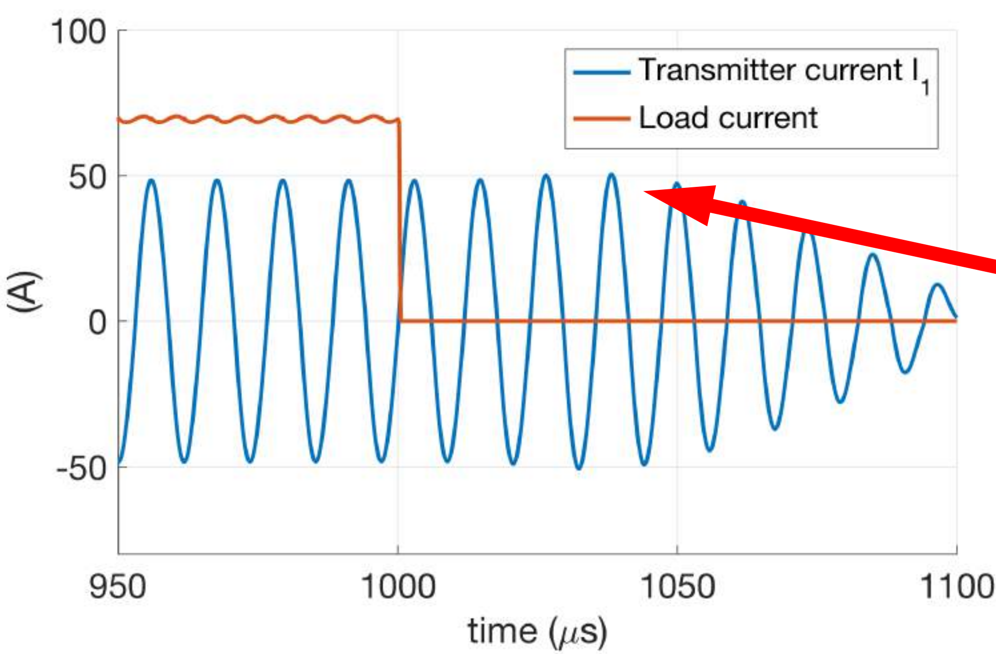
Simulation results





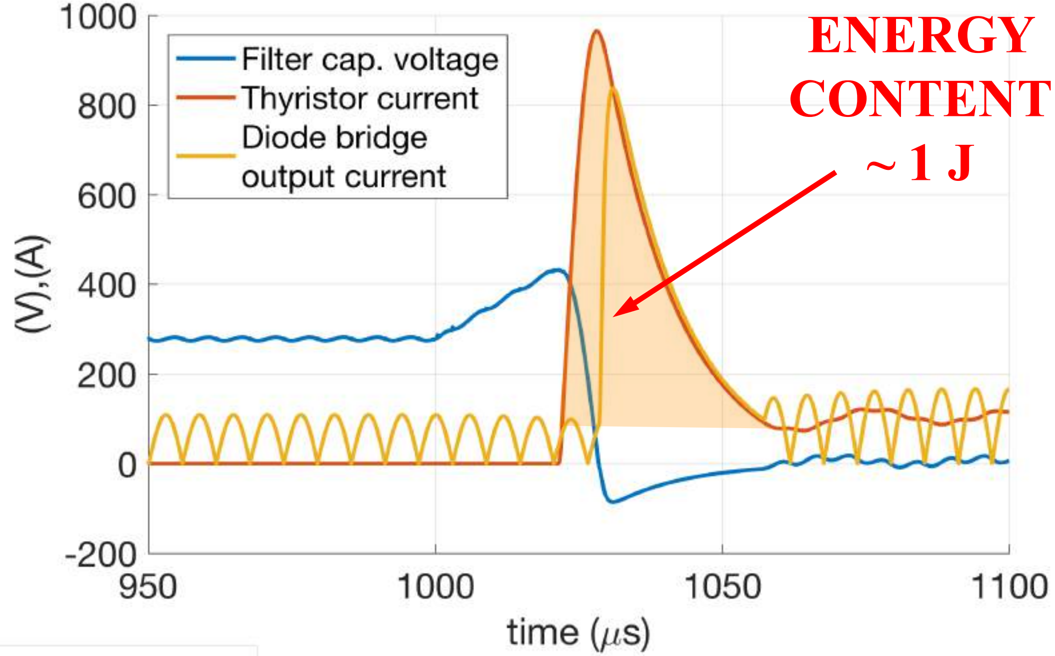
Simulation results



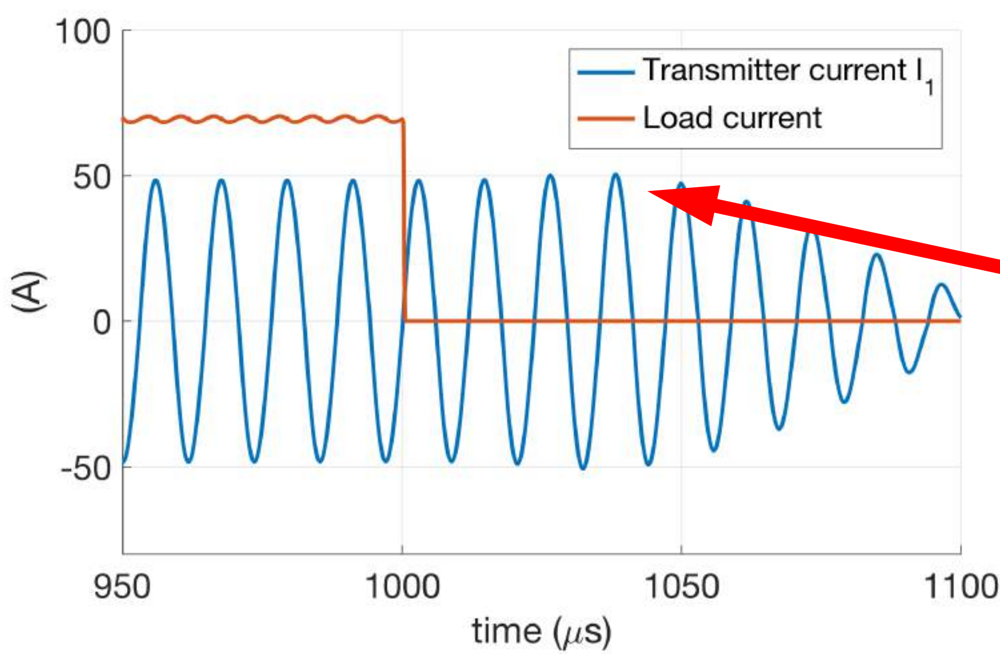


FAULT NOT EASY TO BE DETECTED

Simulation results



ENERGY CONTENT ~ 1 J



FAULT NOT

EASY TO BE

DETECTED

Real implementation

Components	Symbol	Model
Zener diode	D_{z1}	1N5368B
Zener diodes	D_{z2}, D_{z3}	1N5388B
Thyristor	T	MCO150-12io1
Filter capacitors	C_{f1}, C_{f2}, C_{f3}	C4BSPBX4300Z

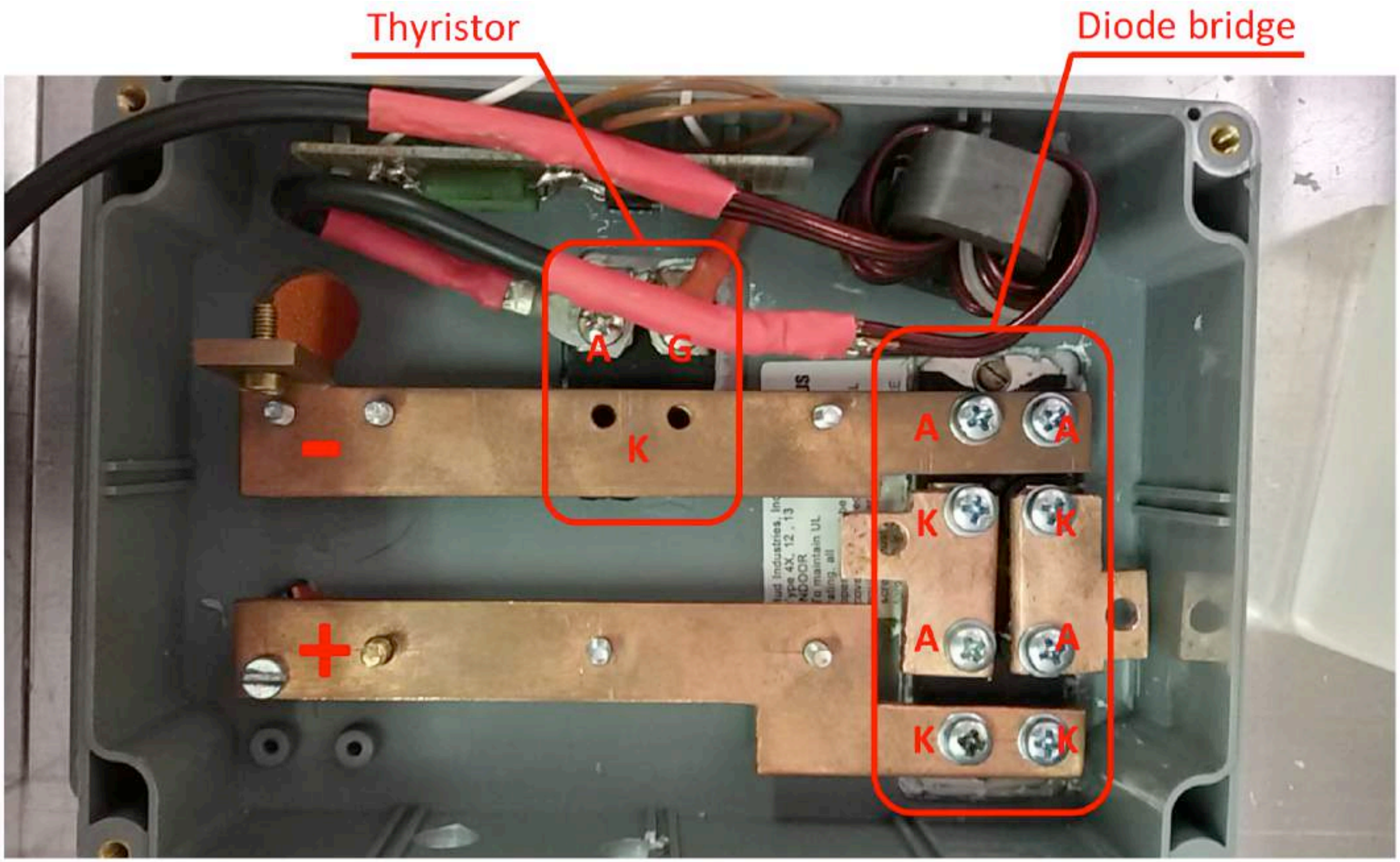
Real implementation

Components
Zener diode
Zener diodes
Thyristor
Filter capacitors

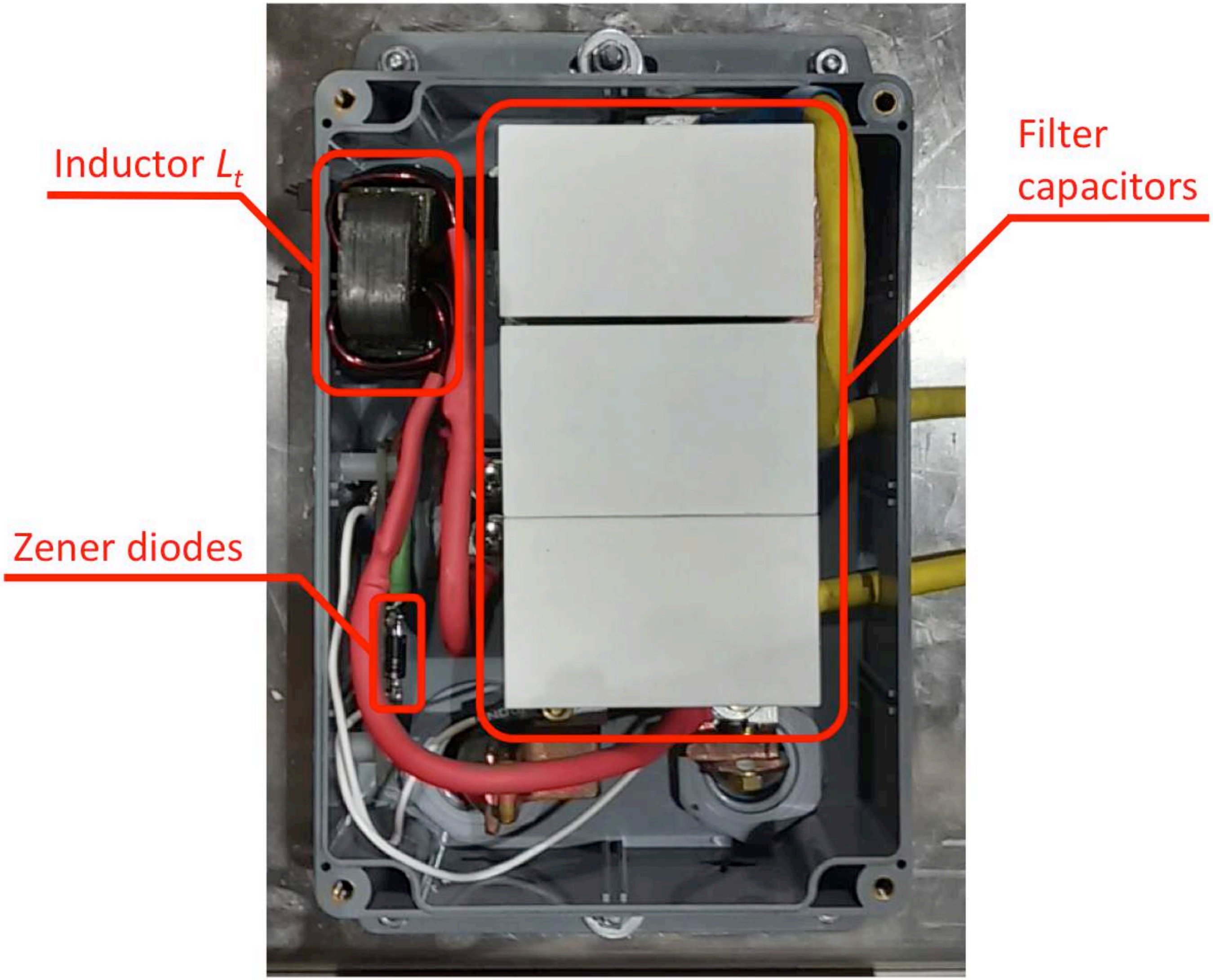
Thyristor ←
Rated curr = 150 A,
Max. Forwad surg. Curr = 2 kA
Max. current rate of rise = 500 A/us

SAFETY FACTOR 2 WITH RESPECT TO SIMULATION RESULTS

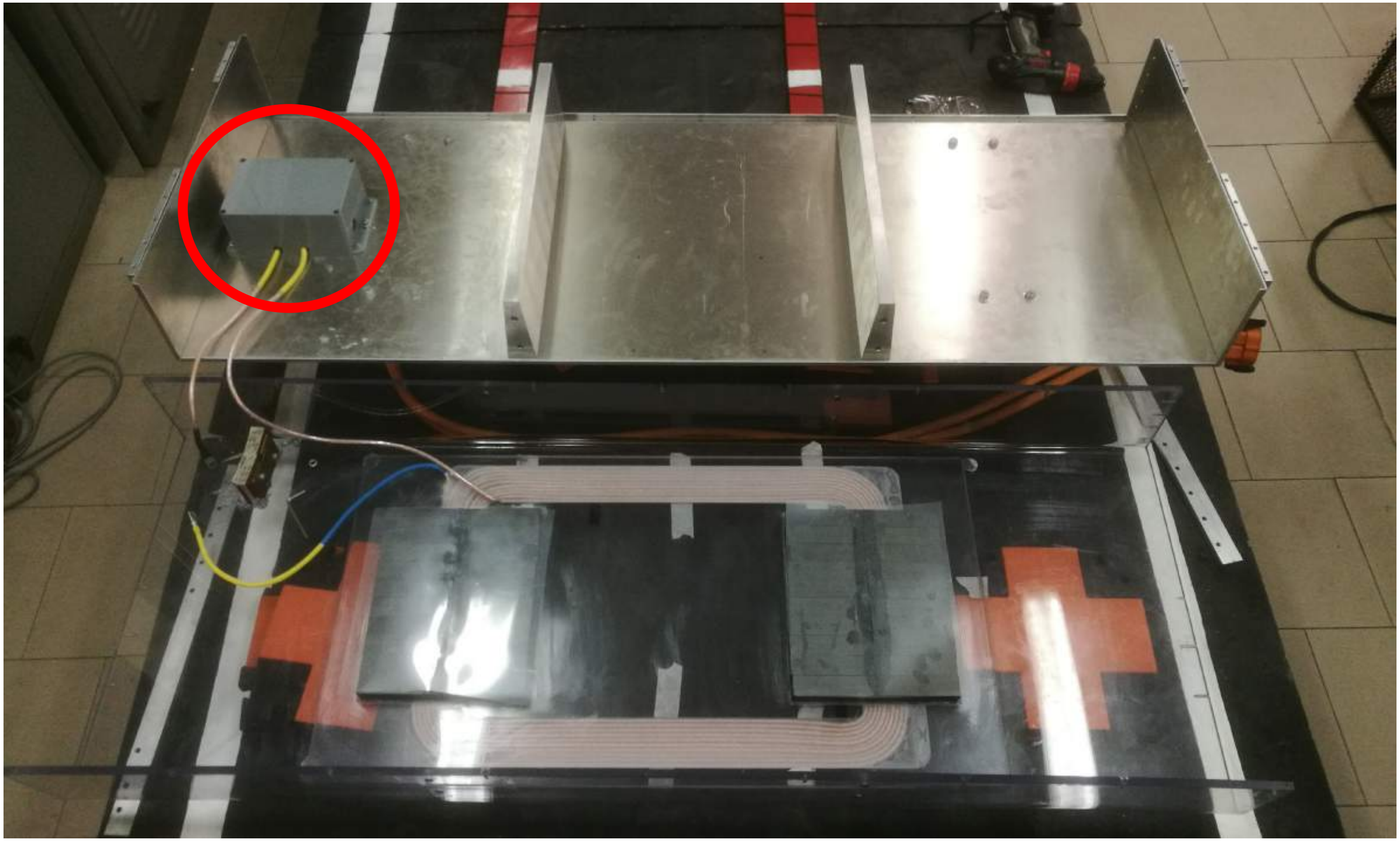
Real implementation



Real implementation



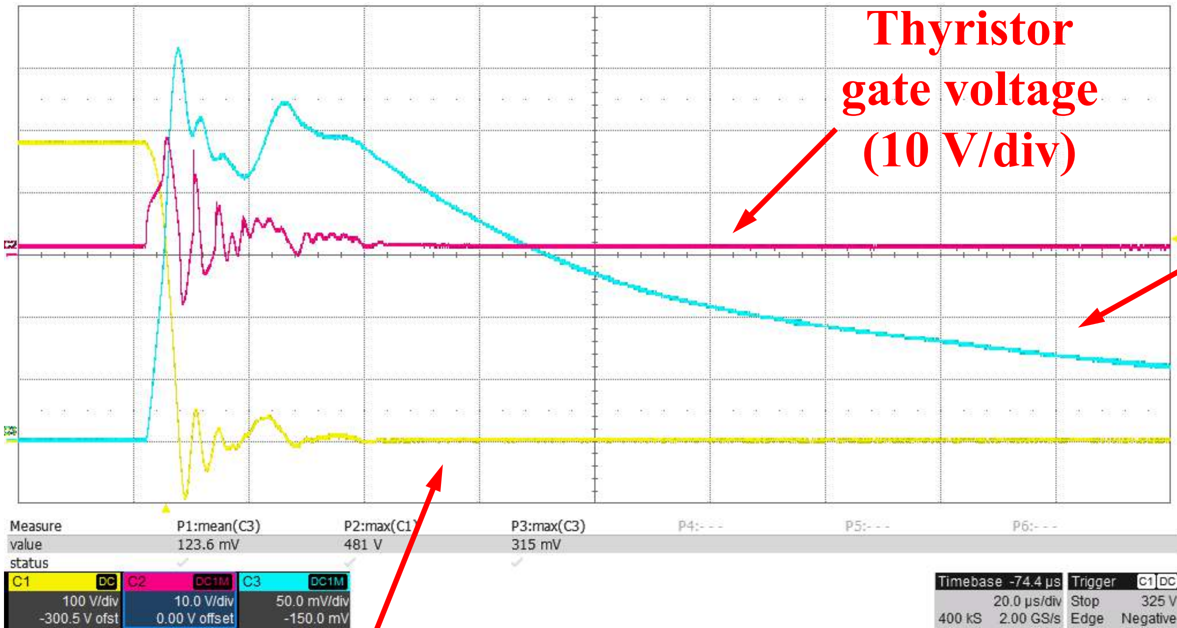
Real implementation



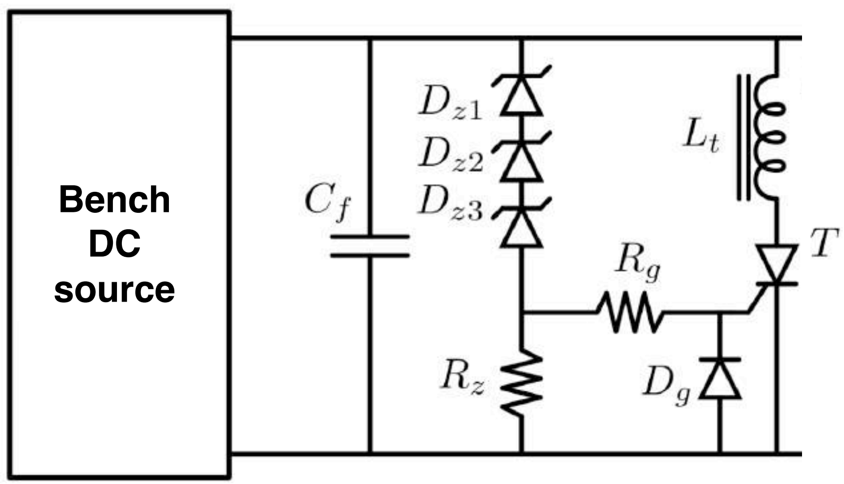
Laboratory test

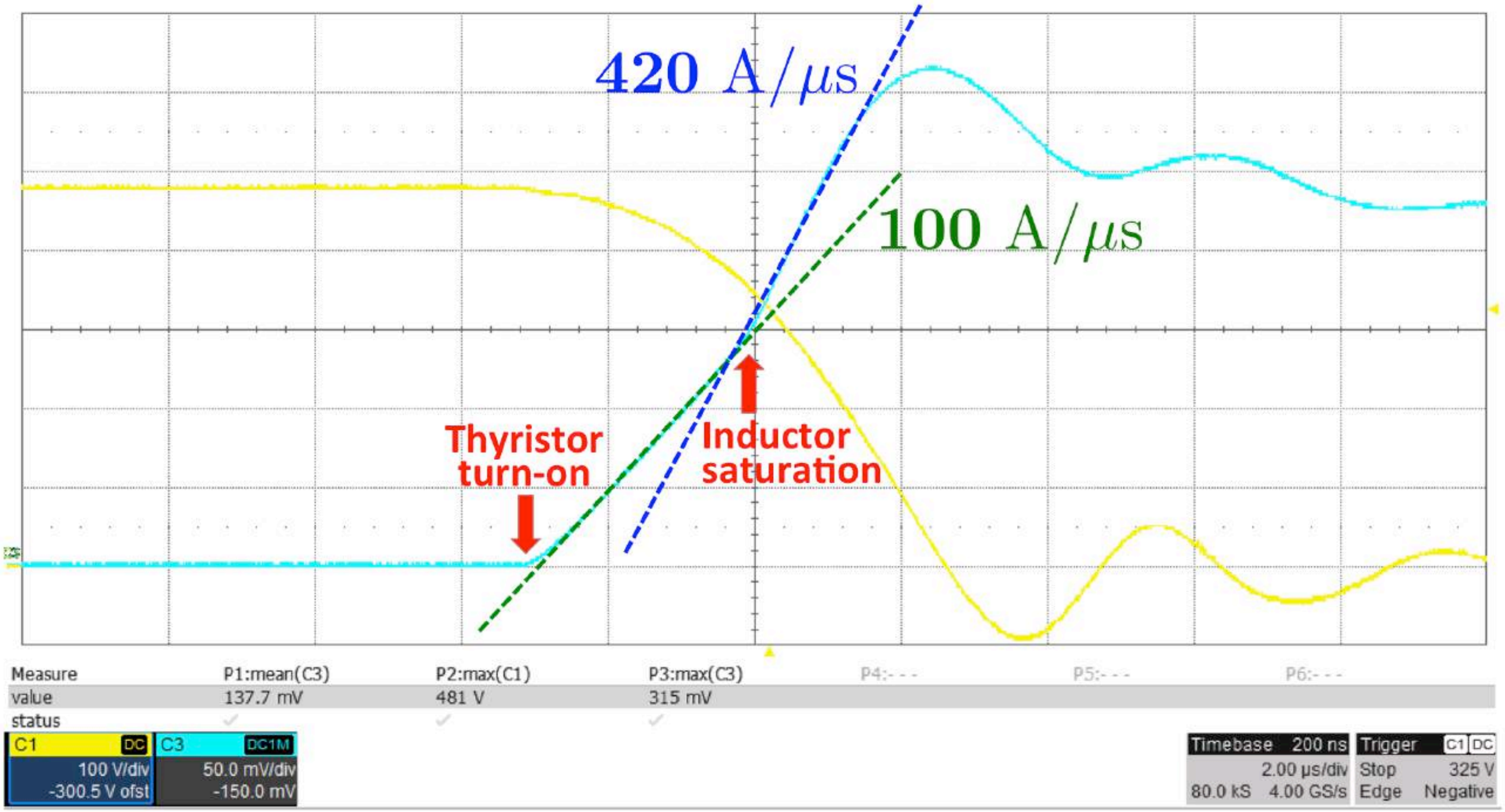
Thyristor gate voltage (10 V/div)

Thyristor current (250 A/div)



Capacitor voltage (100 V/div)




420 A/μs
100 A/μs
Thyristor turn-on
Inductor saturation
Measure
value
status
P1:mean(C3)
137.7 mV
P2:max(C1)
481 V
P3:max(C3)
315 mV
P4:- - -
P5:- - -
P6:- - -
C1 DC
100 V/div
-300.5 V ofst
C3 DC1M
50.0 mV/div
-150.0 mV
Timebase 200 ns
2.00 μs/div
80.0 kS 4.00 GS/s
Trigger C1 DC
Stop 325 V
Edge Negative

Conclusions

- The implemented fast hardware protection resulted effective
- It is based on few simple components
- It does not need to be controlled
- Automatic recover if the fault does not perstist
- The fault can be detected from the trasmitter side that can turn-off the system

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Thank you!

Any question?

You can write me at vincenzo.cirimele@polito.it

Acknowledgments: