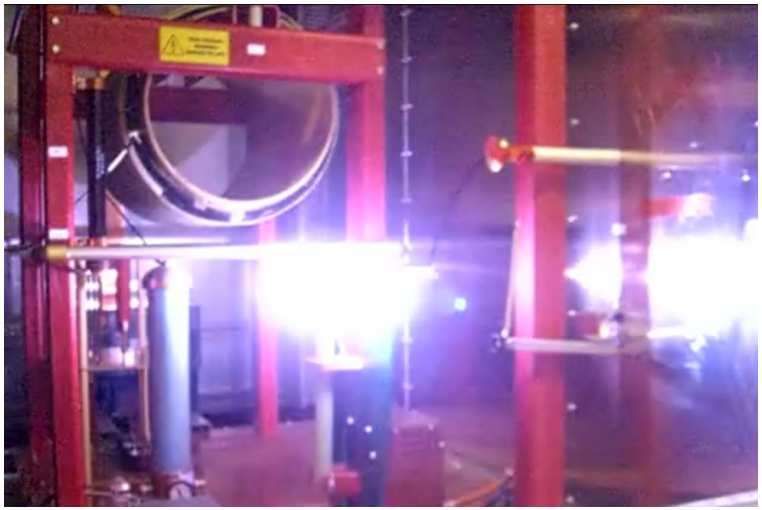
SHORT CIRCUIT ENERGY

CONSIDERATIONS USING THE EXAMPLE OF A PULSE STEP MODULATOR BASED HVPS



CWRF 8. – 11. May 2012

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SHORT CIRCUIT ENERGY

Content

- Motivation: Why this topic?
- Tube Specifications
- How can the arc energy be measured or calculated
- HVPS Stored Energy
- Energy dissipation / arc energy
- Reduction of arc energy
- Inverse Voltage- System
- Summary

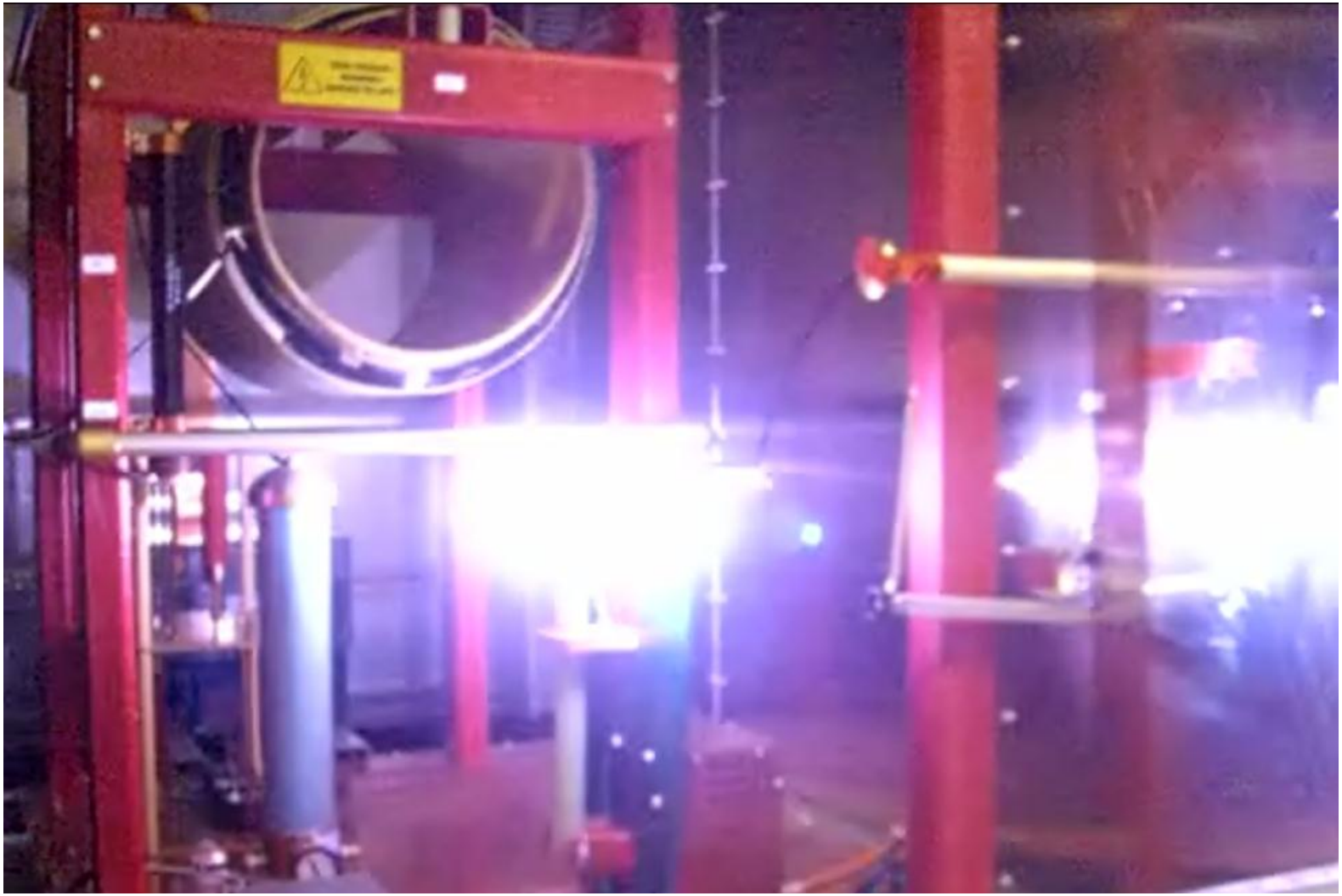
MOTIVATION

- ***Why this topic?***
  - Questions during bids and acceptance tests
  - Increasing filter / ripple requirements → what are the limitations?
  - Frequently discussed issue: Cable length between the supply and the tube
  - Important for a safe tube operation
  - To give an idea / feeling about the figures

What is the energy dissipated in a load (tube) arc?

- ***Arc energy specifications***
  - Usually in the region of 10..20 Joule
  - 15 Joule corresponds to 15 bars of chocolate lifted 1m.

VERIFICATION



VERIFICATION

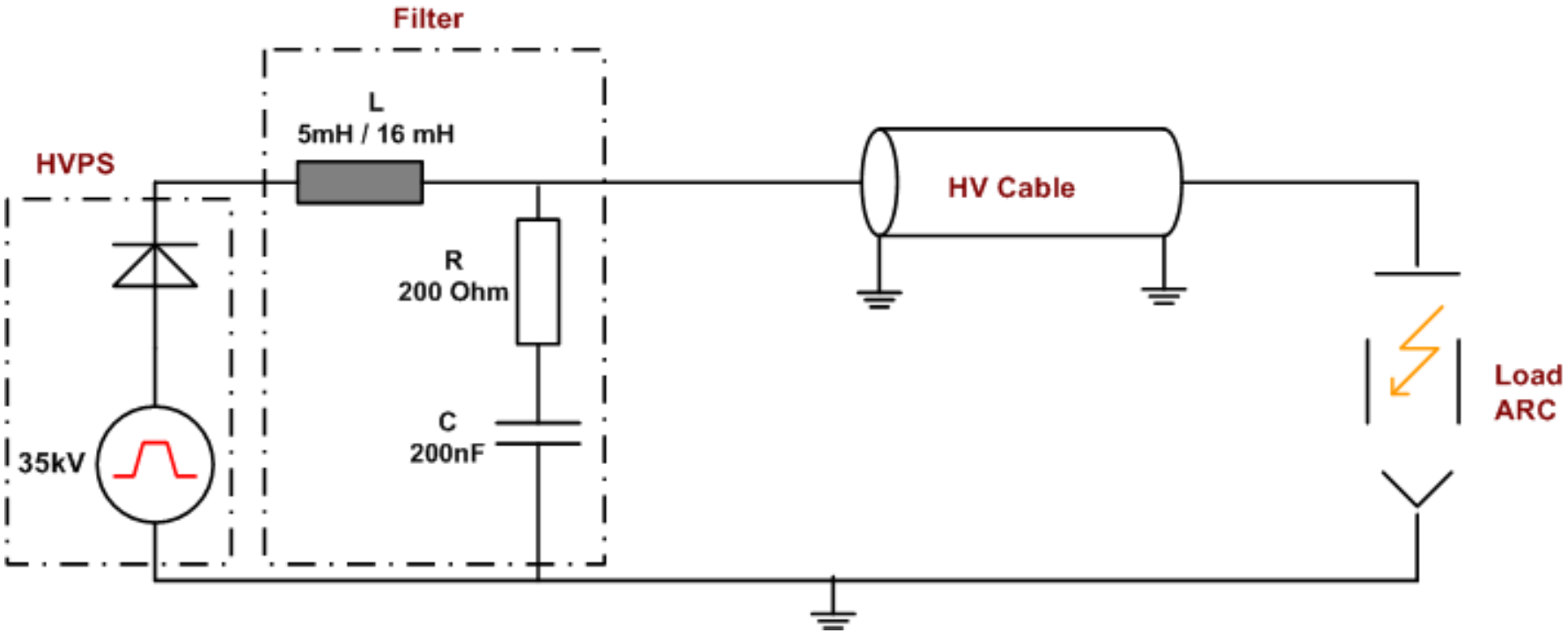
Measuring the arc energy

- Simple test with a wire as proposed in tube Datasheets
- Using a real fuse I2t value
- Accurate Current measurement is possible (e.g. pearson coil, coaxial shunt)
- Accurate Arc Voltage measurement is not easy to do
- We proposal: Measuring the current and post-calculating the energy dissipation with a defined arc Model

Calculating the arc energy

- Arc Model Proposal for vacuum tubes: Series connection of DC Voltage source 100V and Resistor 200mOhm.
- Simulations provide good basis for later verification
- System optimization can be easily done in simulations

BASIC MODEL



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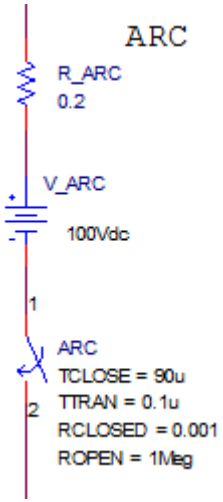
STORED ENERGY

- Basic model with a 2 – pole RLC filter network
- System parameter 35kV / 3.5A, a rather small system.
- ARC energy specifications **15** Joule
- Stored energy is much higher

Parameter	Value	Stored Energy
Filter Inductor	16 mH 5 mH	0.1 Joule / 6 Joule 0.03 Joule / 15 Joule
Filter Capacitor	200nF	123 Joule
High Voltage Power Supply	60 modules 57 Joule / module	3420 Joule
Cable	100 pF / meter	0.06 Joule / meter

ENERGY DISSIPATION

- ***Where is the energy dissipated in case of a short?***
  - What happens with the stored energy in the filter QL QC?
  - Simulation model parameters:
    - Turn off delay 10 us
    - Voltage drop in the diodes: 2V / Diode
    - Short circuit model: 100V / 0.2 Ohm



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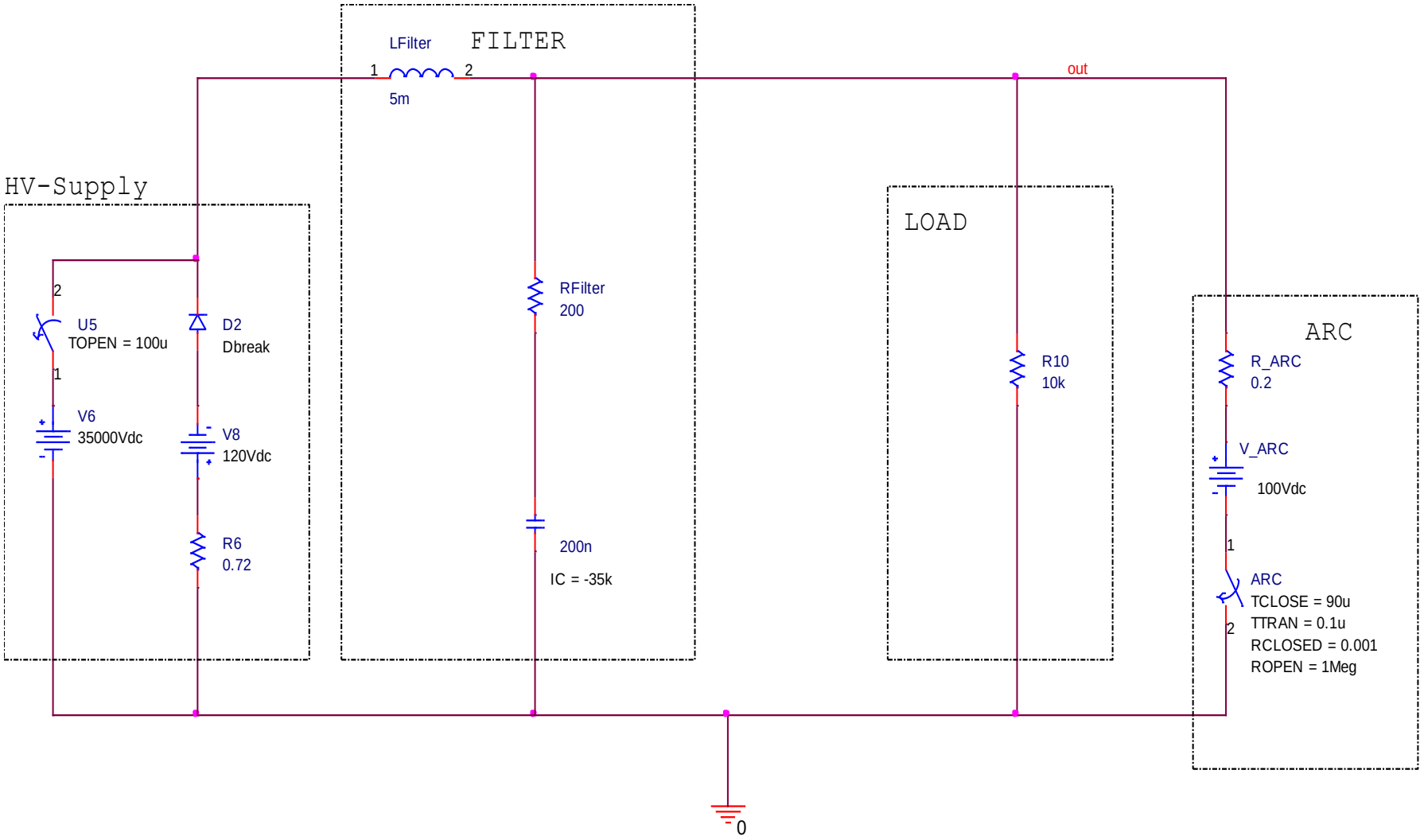
SIMULATION MODEL



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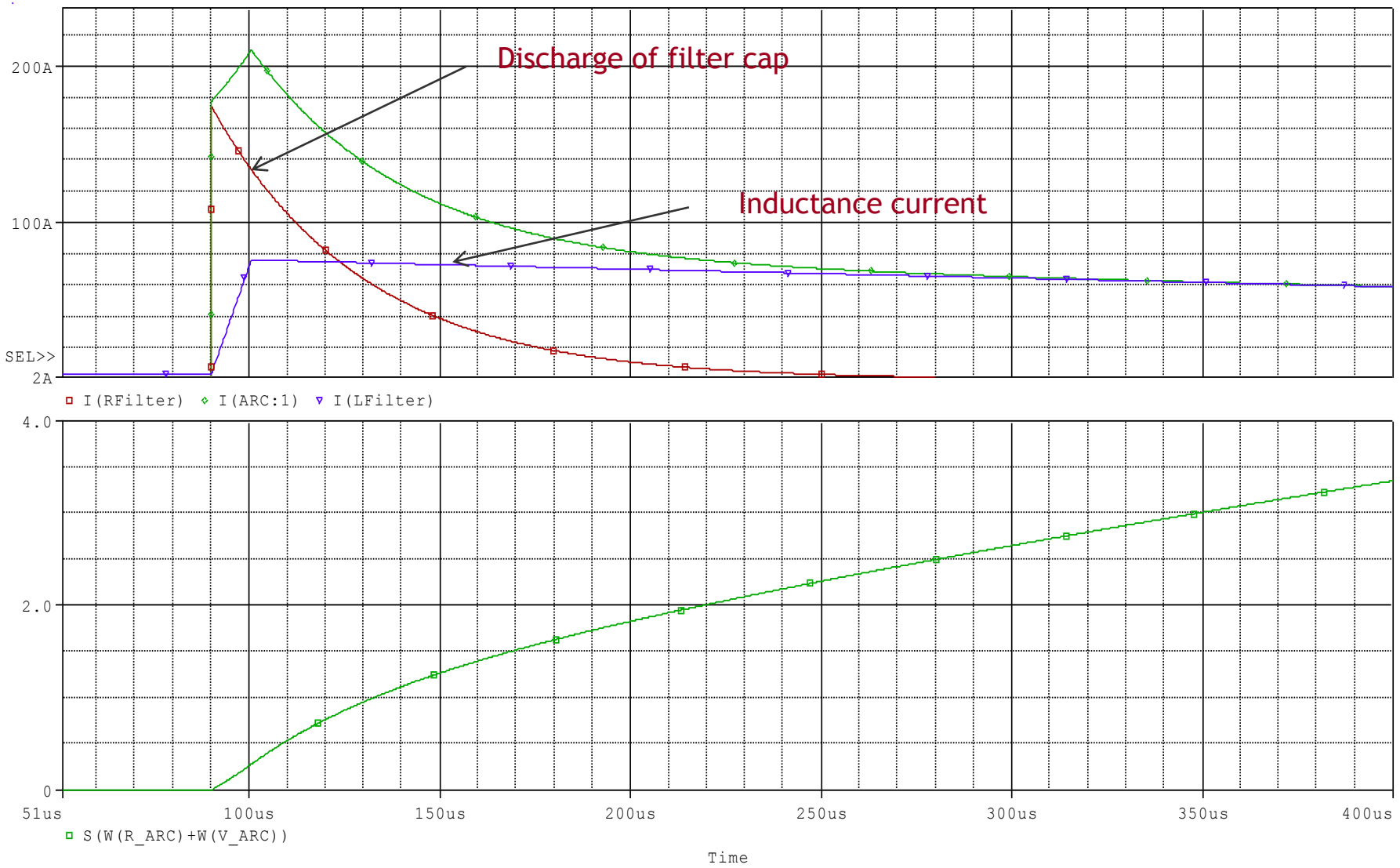
SIMULATION: 5 MH FILTER INDUCTANCE



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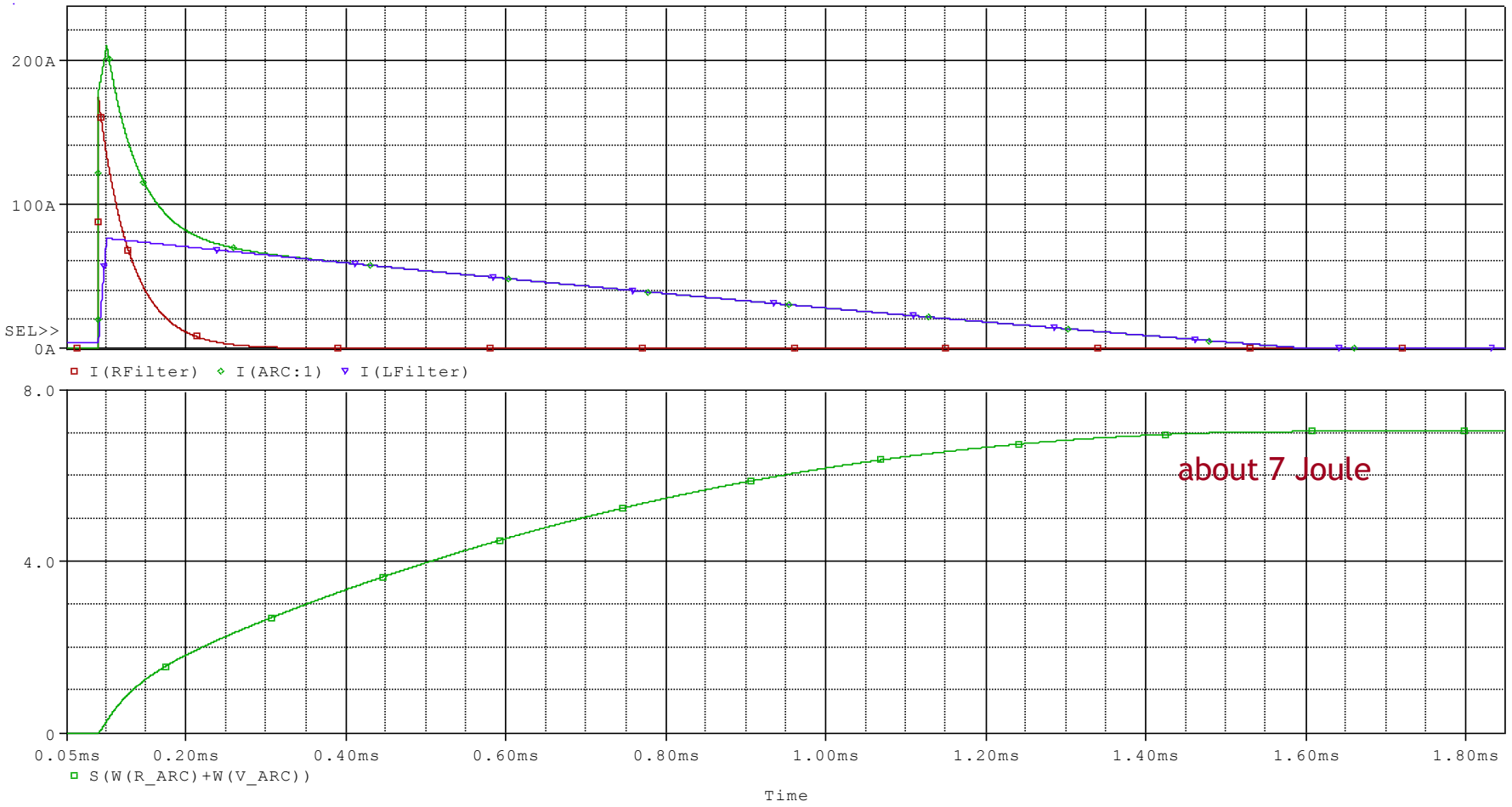

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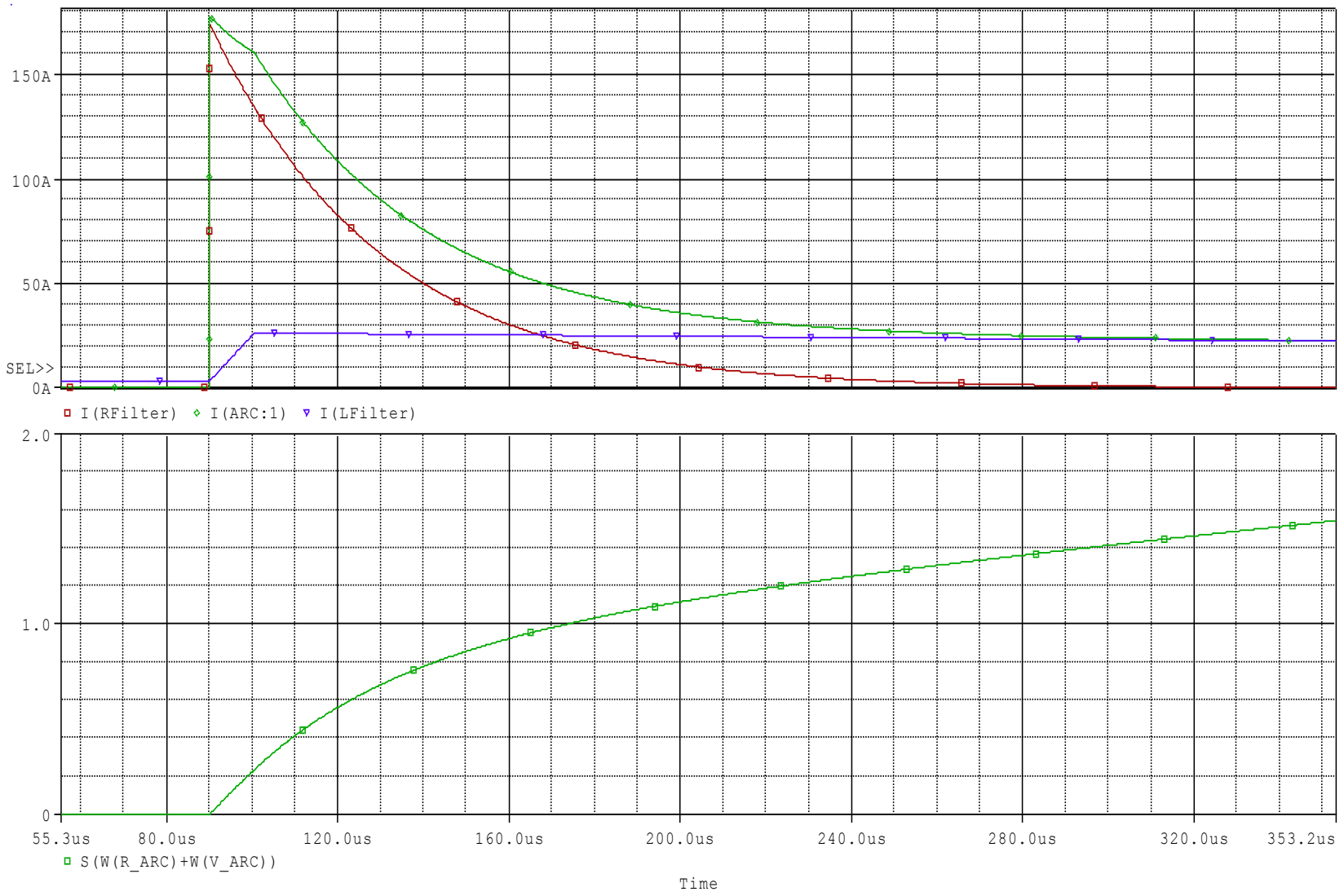
SIMULATION: 16 MH FILTER INDUCTANCE



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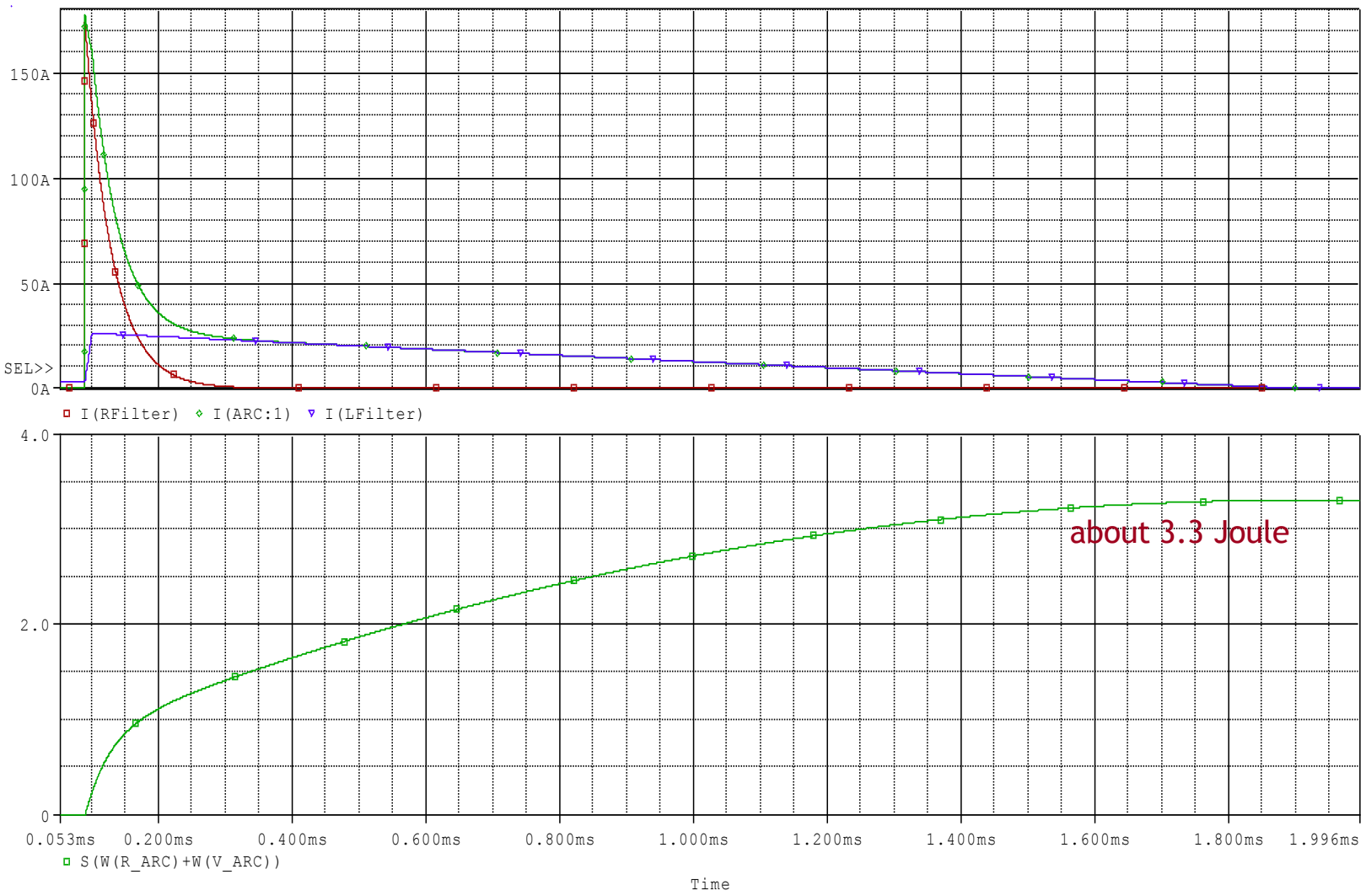

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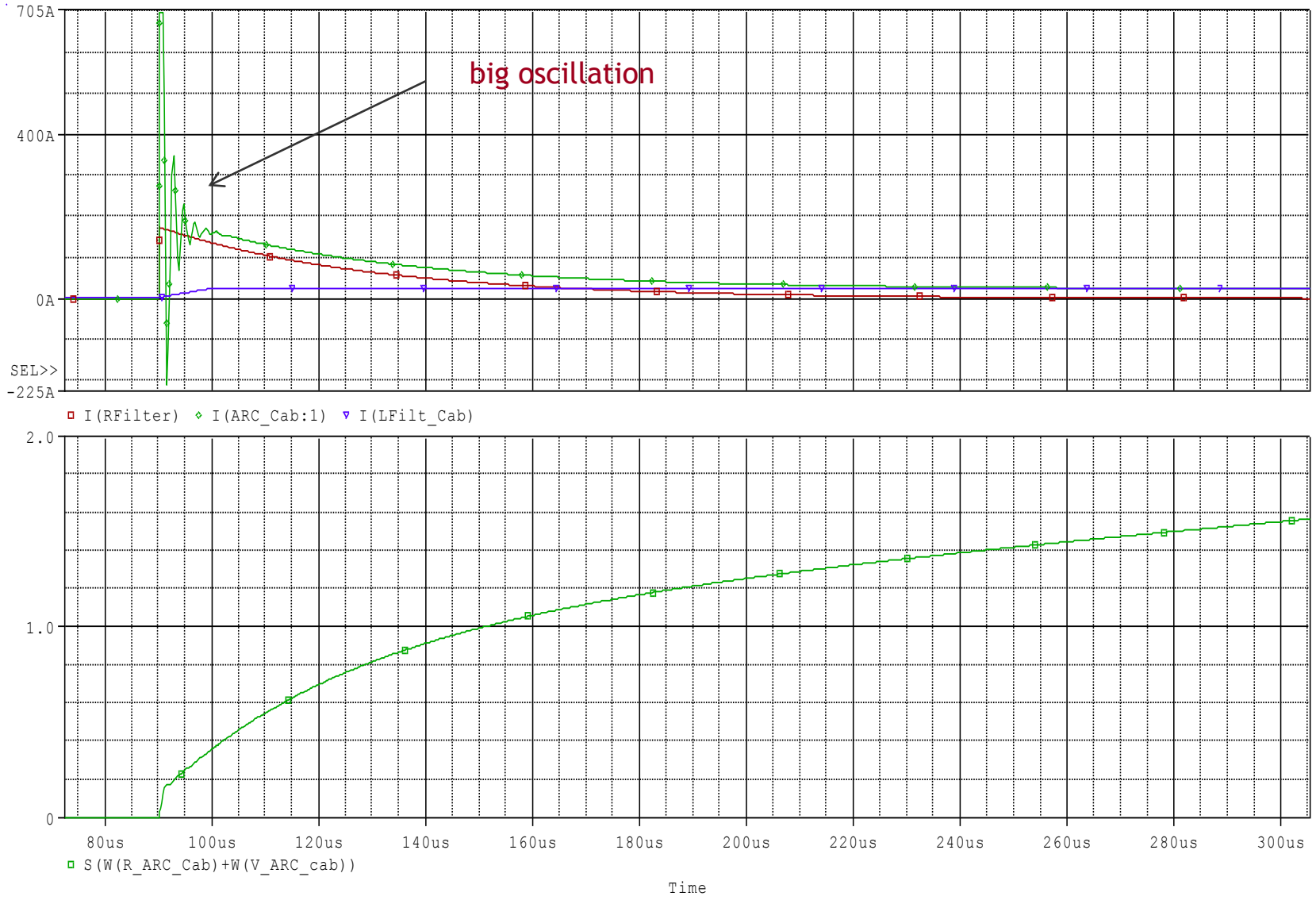
SIMULATION: WITH CABLE

100 METER CABLE ADDED TO THE SIMULATION



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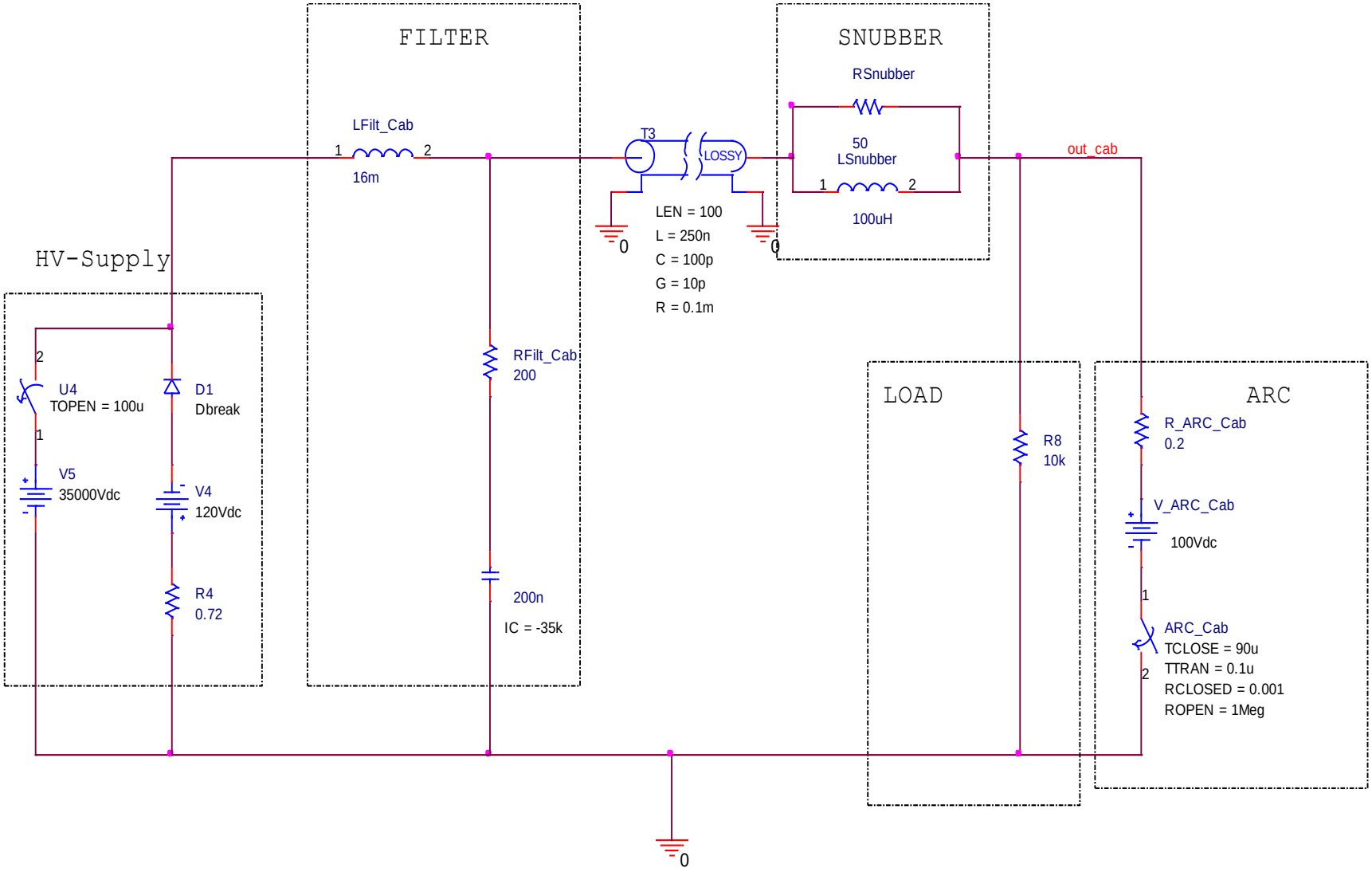
SIMULATION: WITH CABLE AND SNUBBER



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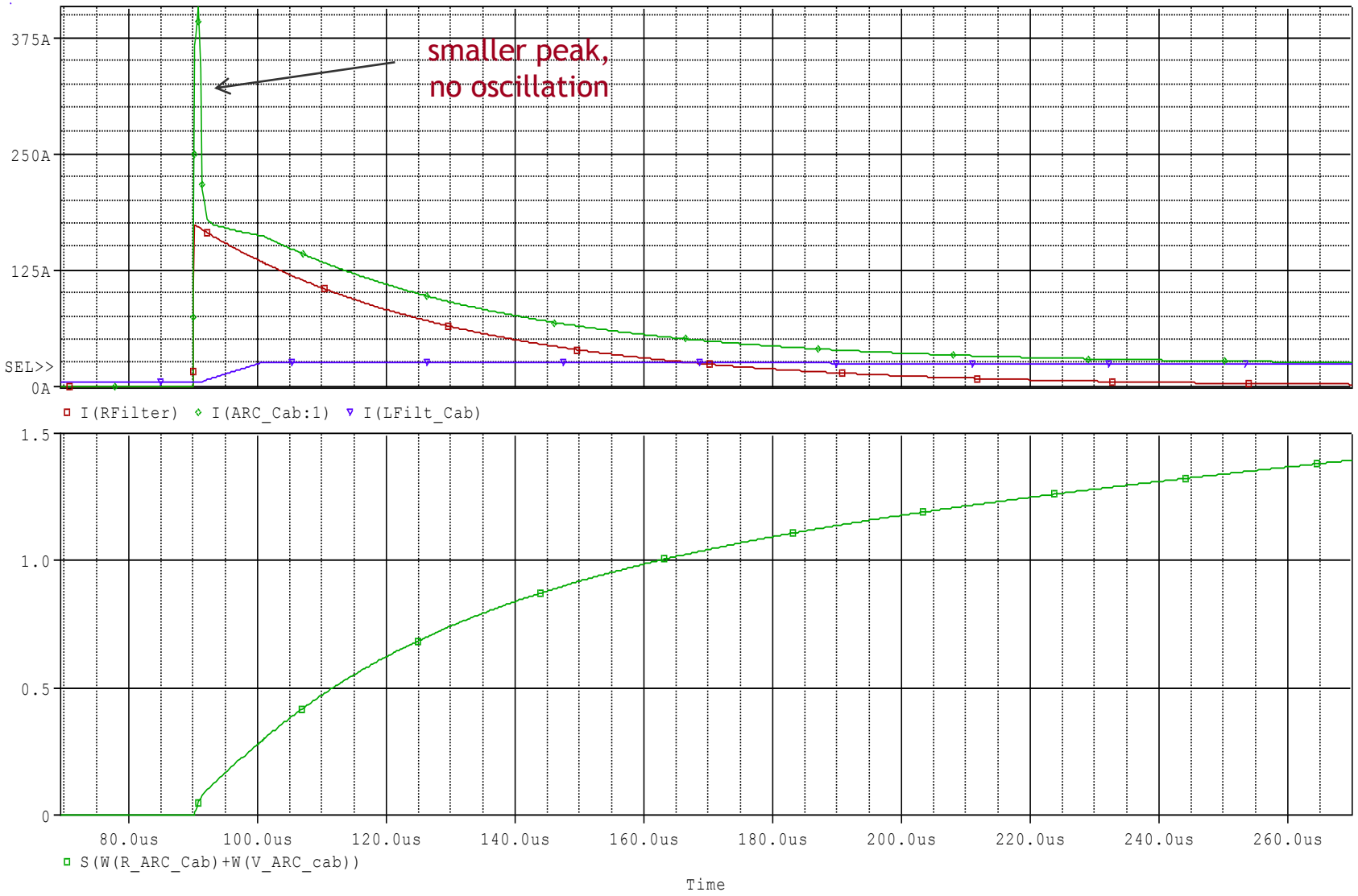

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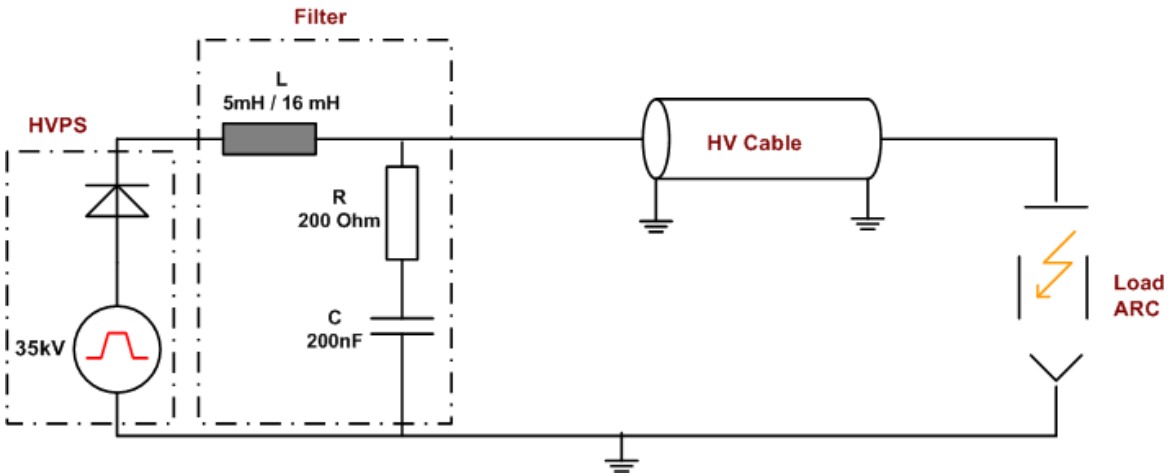
ENERGY DISSIPATION SUMMARY

- ***Where is the energy dissipated in case of a short?***
  - Filter Capacitor:
    - Almost everything is dissipated in the filter resistor
  - Filter Inductance:
    - Before shutdown of the PSM the L is charged → Energy
    - After PSM shutdown the energy is dissipated in the short and the diodes of the PSM
  - Cable snubber are reducing oscillations and Arc Energy



OPTIMIZATION

- ***How can the energy be reduced, measures?***
  - Filter can be optimized according operating point.
  - More complex filters instead a simple RLC network.
  - Tradeoff: Filter vs. Energy
  - Using Cable Snubbers for long cables
  - Thomson patented Inverse voltage Operation Mode

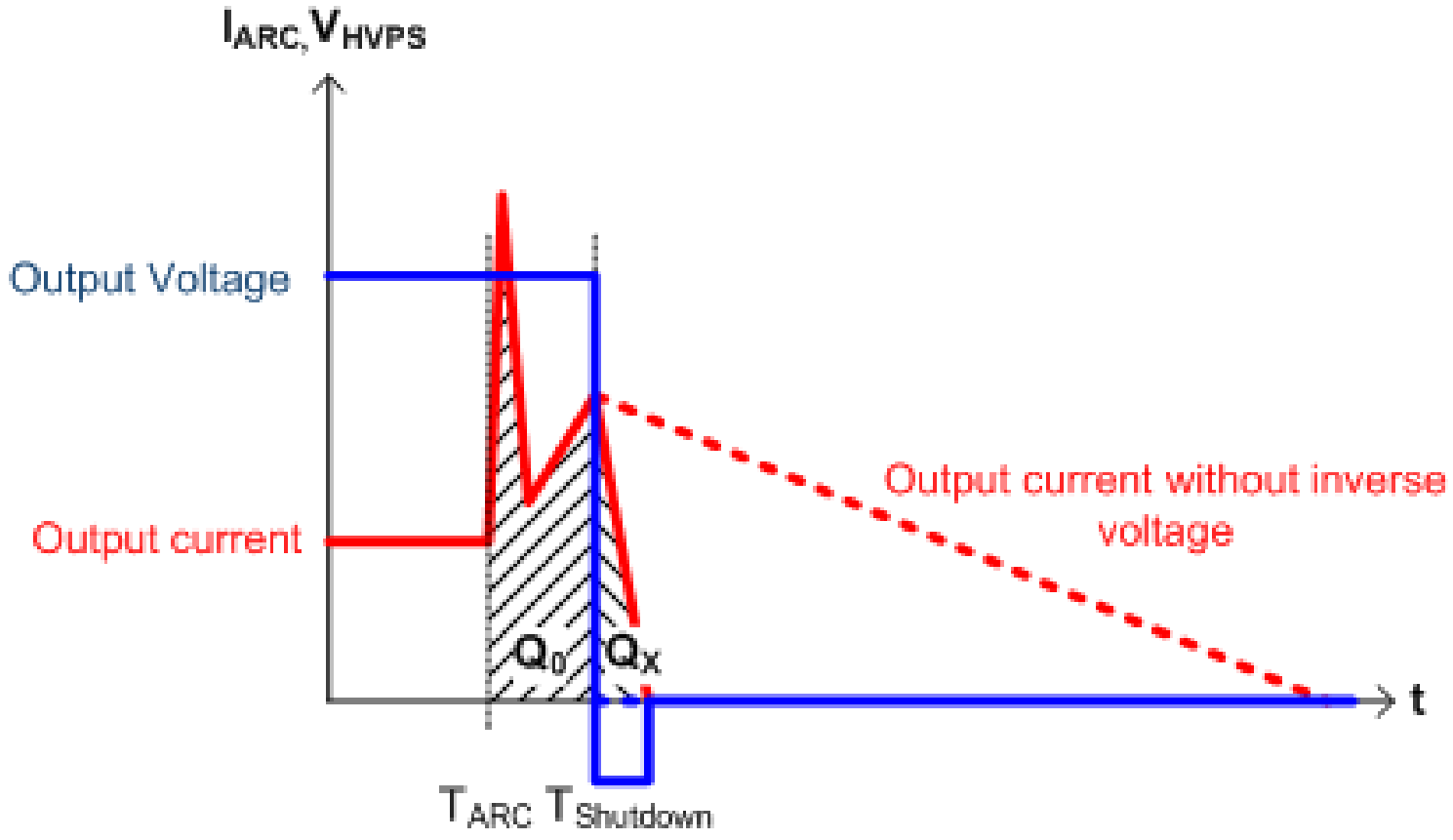
KGP5: INVERSE VOLTAGE OPERATION

Application example: KGP5 Test stand for Tubes

- 160 kV / 3.2 MW CW
- Higher power in pulsed mode
- 5 us Rise time
- Arc energy can be **set between 2 Joule and 20** Joule
- This specifications required new solution:
  - **Inverse Voltage Operation Mode**

KGP5: INVERSE VOLTAGE OPERATION

Principle



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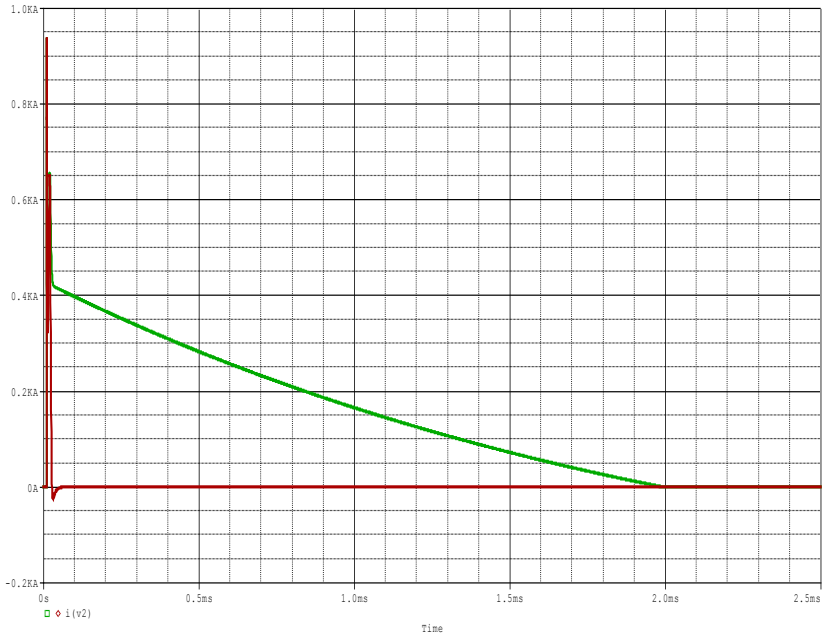
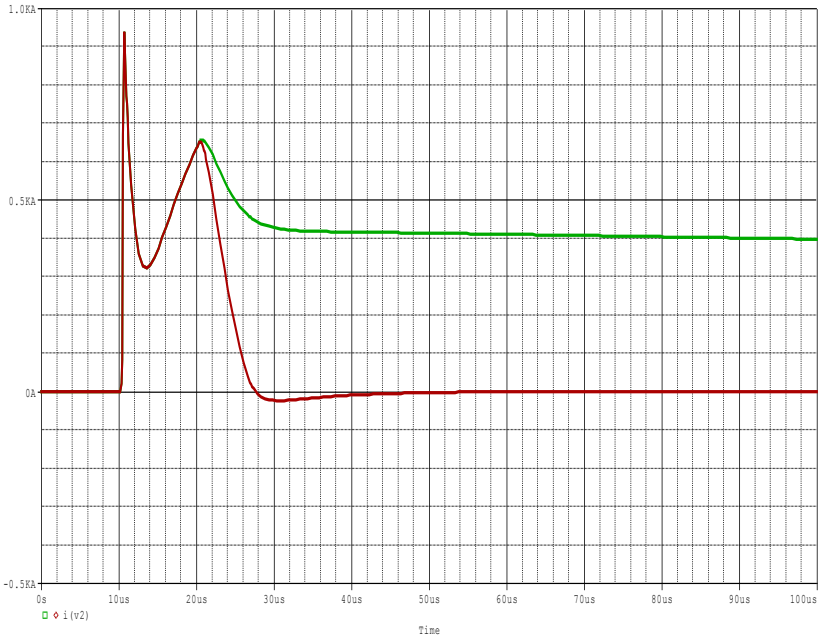
KGP5: INVERSE VOLTAGE OPERATION

Short Circuit Current Simulations

- Green: output current without inverse voltage operation
- Red: output current with inverse voltage operation





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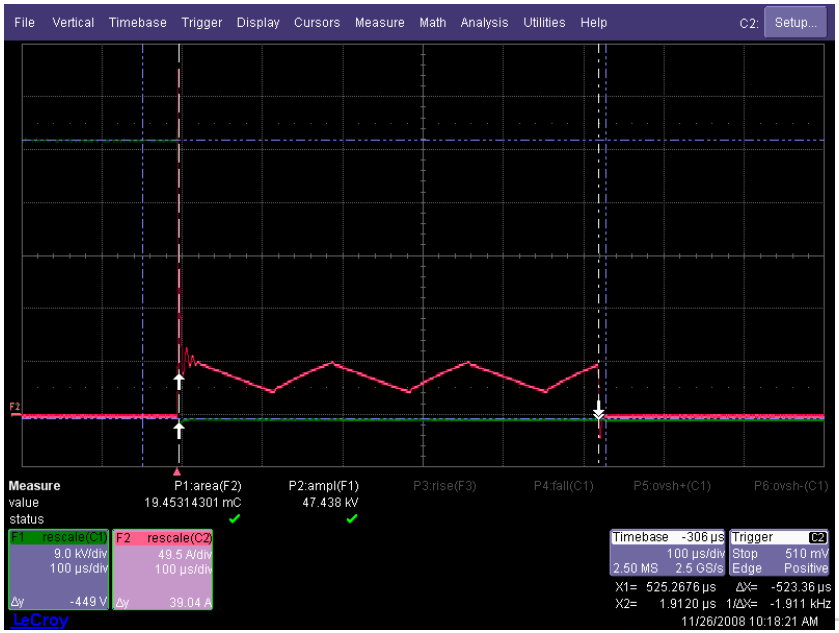
KGP5: INVERSE VOLTAGE OPERATION

- ***Short circuit Test on Tube teststand***
  - Adjustable arc energy 2 – 20J
  - Main Issue with IVO was the 20J not the 2J → 2Point Regulation implemented
  - Top Trace:
    - Vout = 102kV; Energy Setting = 2.5J
    - Charge Measured 29mAs (2.9J @100V)
  - Bottom Trace:
    - Two point regulation until energy is reached



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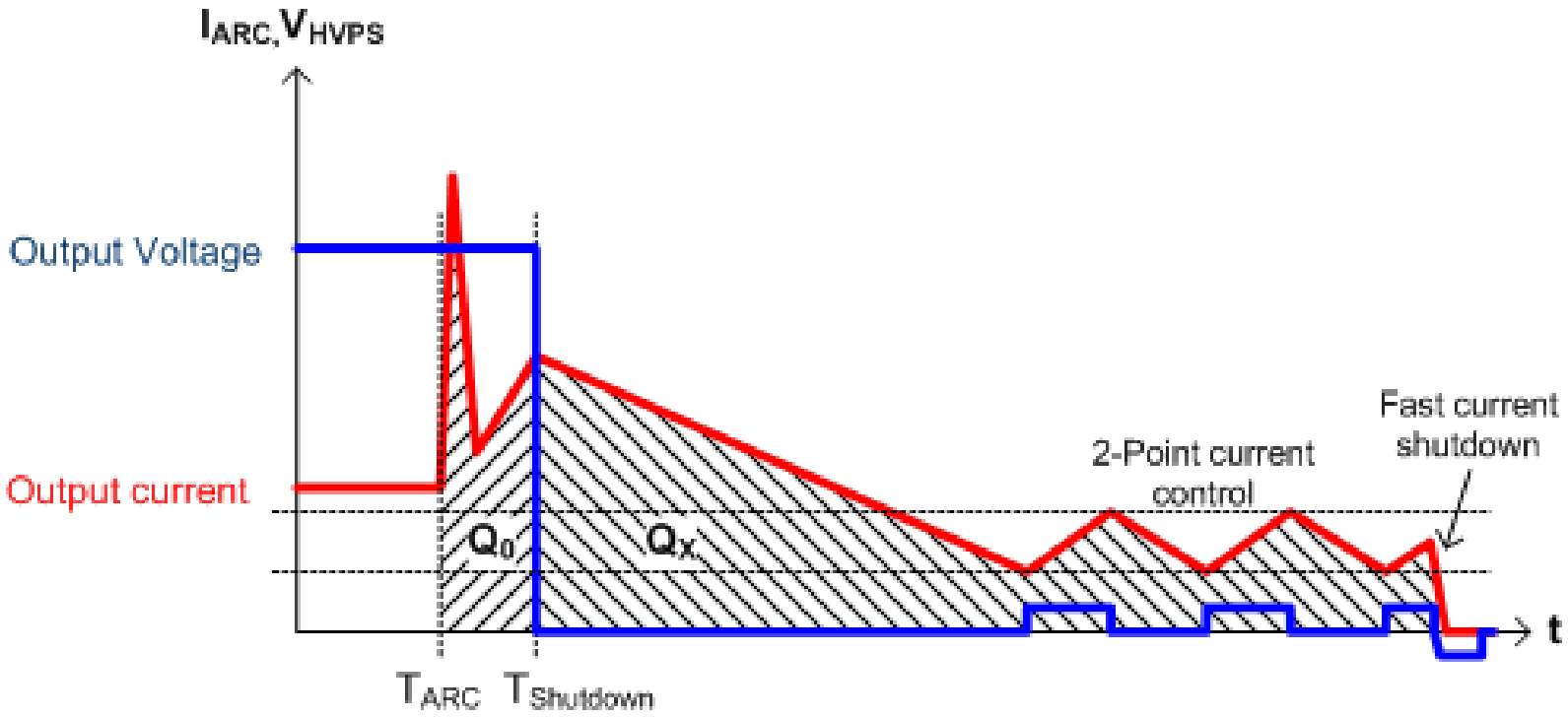
KGP5: INVERSE VOLTAGE OPERATION

- ***Two point regulation for a defined Q***



SUMMARY

Summary

- Bigger capacitors or inductors des not necessarily mean more energy in the arc.
- Considering the whole system is important!
- Degrees of freedom allow optimization → therefore it is important to know the real requirements.
- May be an iterative process together with the customer.
- Thomson's Inverse Voltage Supplies can reduce the energy to a minimum.

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BROADCAST

THANK YOU