

# Modular Highly Dynamic and Ultra-Low Ripple Arbitrary Current Source for Plasma Research

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- **Multi-purpose, flexible, modular current source**
- **Applications:**
  - DC-arc research for HVDC circuit breakers
  - Bumper/Septum magnets
  - Plasma sources
- **Requirements:**
  - High dynamic
  - Low ripple
  - Arbitrary current waveform
  - High modularity

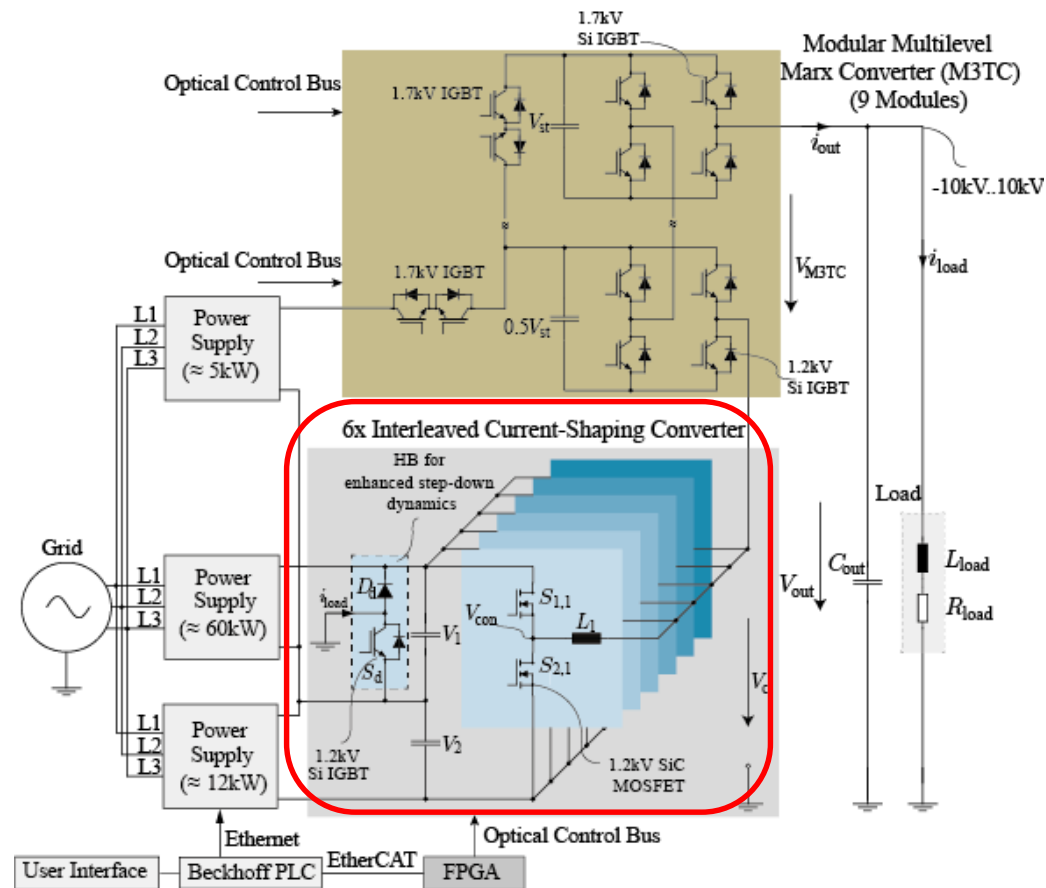
## Outline

- **Introduction**
- **Proposed Topology**
- **Design Considerations**
- **Control System**
- **Simulation Results**

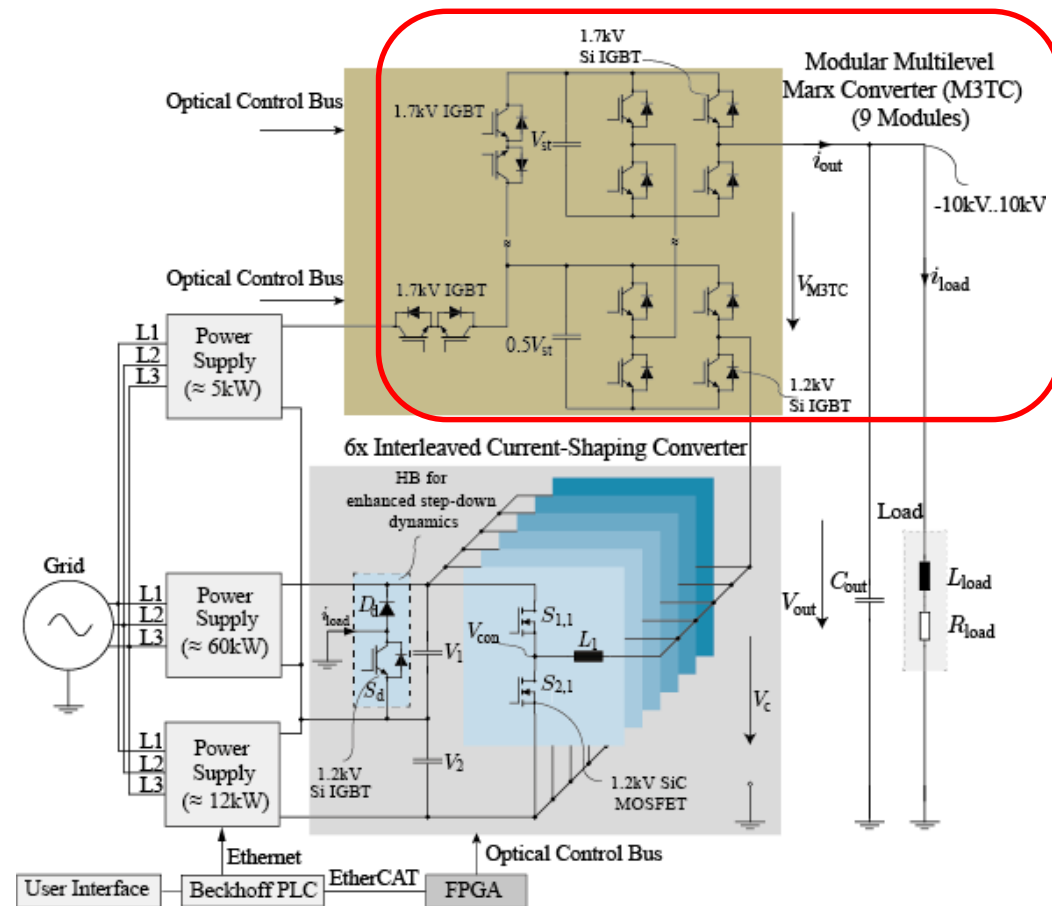


Photo of the first prototype of the modular current source. The prototype was designed and built at the HPE laboratory, ETH Zurich.

- **Multi-phase buck-type current shaping converter**
  - $I_{out} : 0 \dots 1.5\text{kA}$
  - $V_{out} : 0 \dots 600\text{V}$
  - Interleaving  $\rightarrow$  current ripple reduction
  - High  $f_s \rightarrow$  SiC MOSFET
  - Additional HB  $\rightarrow$  enhanced step-down dynamics

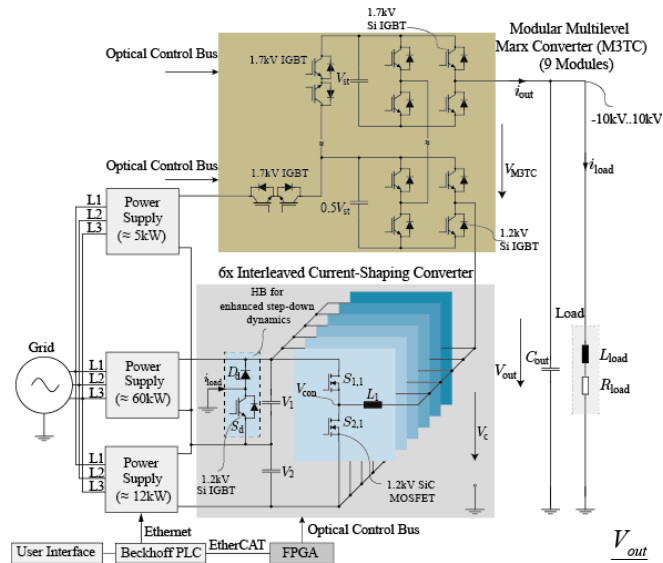


- **Modular Multilevel Marx Converter M3TC**
  - Staircase voltage
  - H-bridge  $\rightarrow$  Bipolar voltage  $\pm 10\text{kV}$
  - Low  $f_s \rightarrow$  slow dynamics



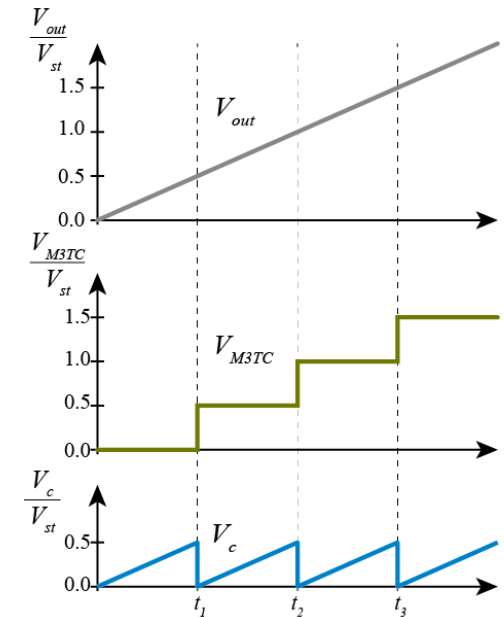
- **Single stack source:**

- $V_{out} : \pm 10kV$
- $I_{out} : 1.5 kA$
- $di/dt : >10A/\mu s$
- $\Delta i_{pp} : <1\%$

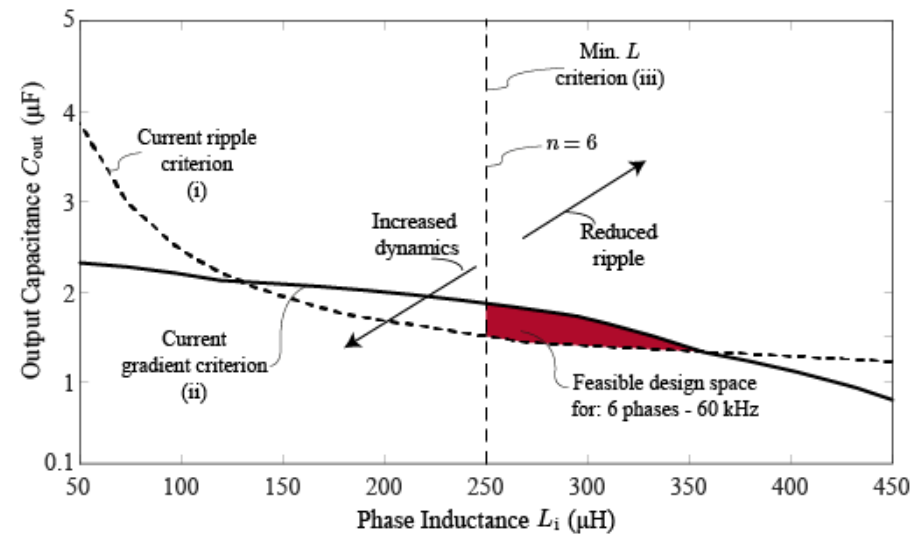


- **Full-scale source:**

- 20 parallel single stacks
- $I_{out} : 30kA$
- $di/dt : >200A/\mu s$
- $\Delta i_{pp} : <0.1\%$



- **Design parameters**
  - Number of modules :  $n$
  - Switching frequency :  $f_s$
  - Inductance :  $L_i$
  - Output capacitance:  $C_{out}$
- **Design constraints:**
  - $\Delta i_{pp} < 1\%$
  - $di/dt > 10A/\mu s$
  - Min.  $L_i$  for robustness



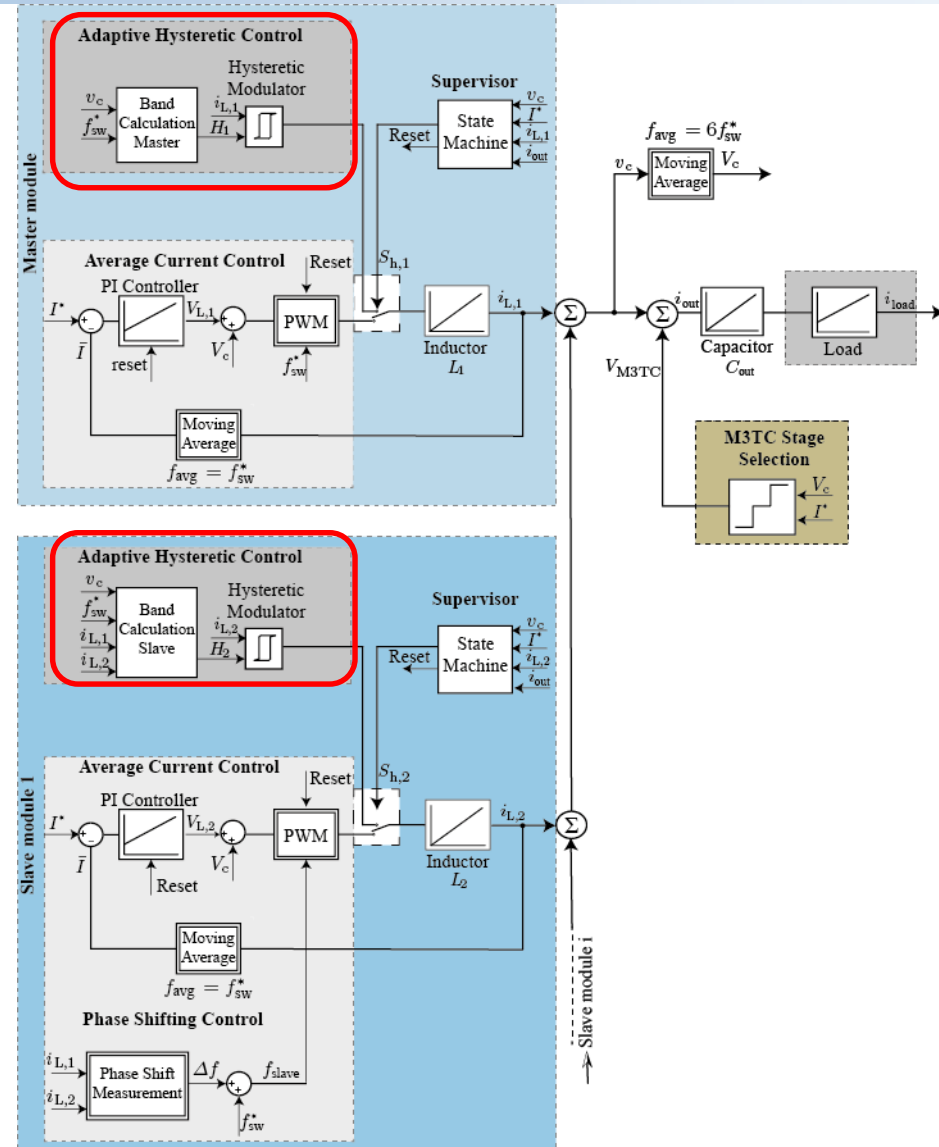
## Resulting parameters of a single stack

$n$	6
$f_s$	60kHz
$L_i$	250μH
$C_{out}$	2μF

- **New adaptive hybrid control concept**

- **Adaptive hysteretic controller**

- ✓ Time-optimal transient response
    - ✓ Excellent disturbance rejection
    - ✓ Design simplicity
    - Poor steady state performance

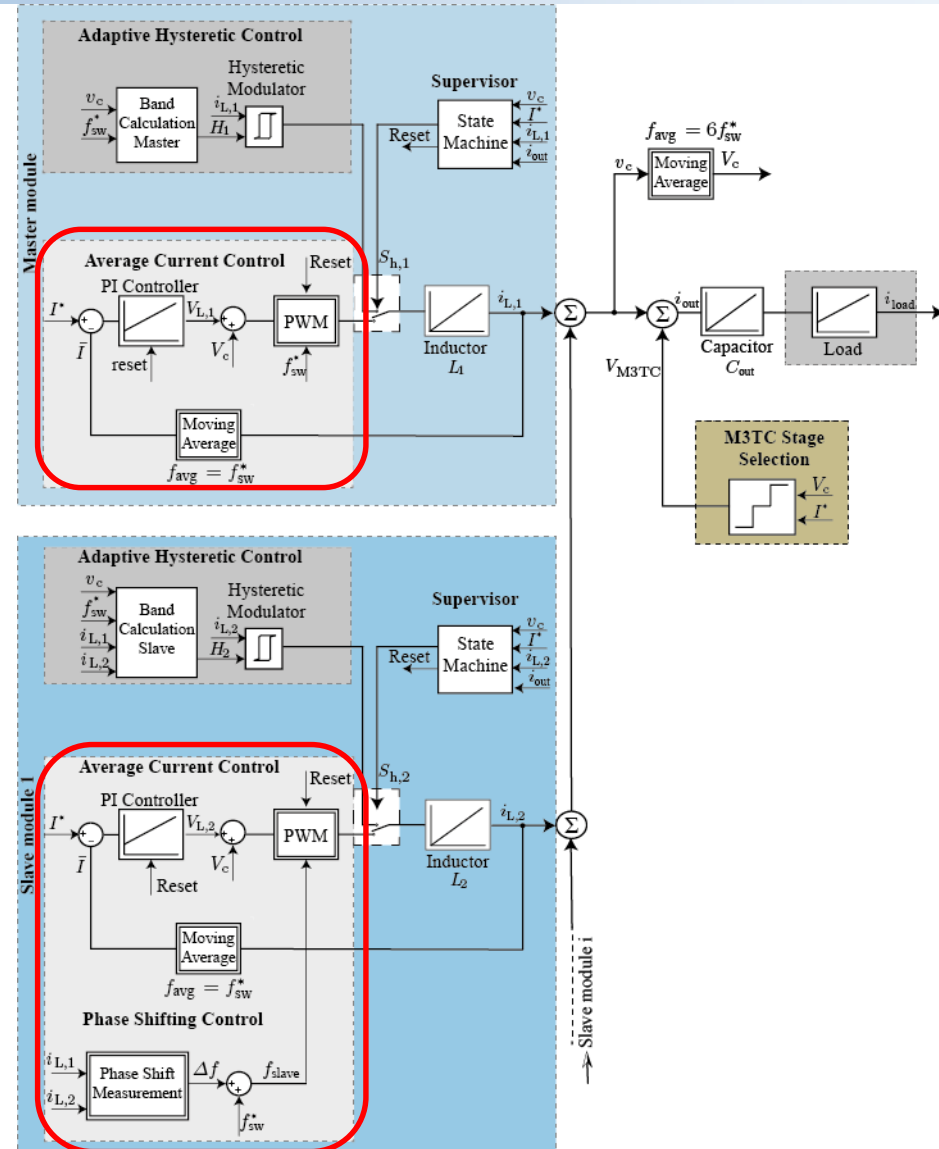


- **New adaptive hybrid control concept**

- **Average Control Mode**

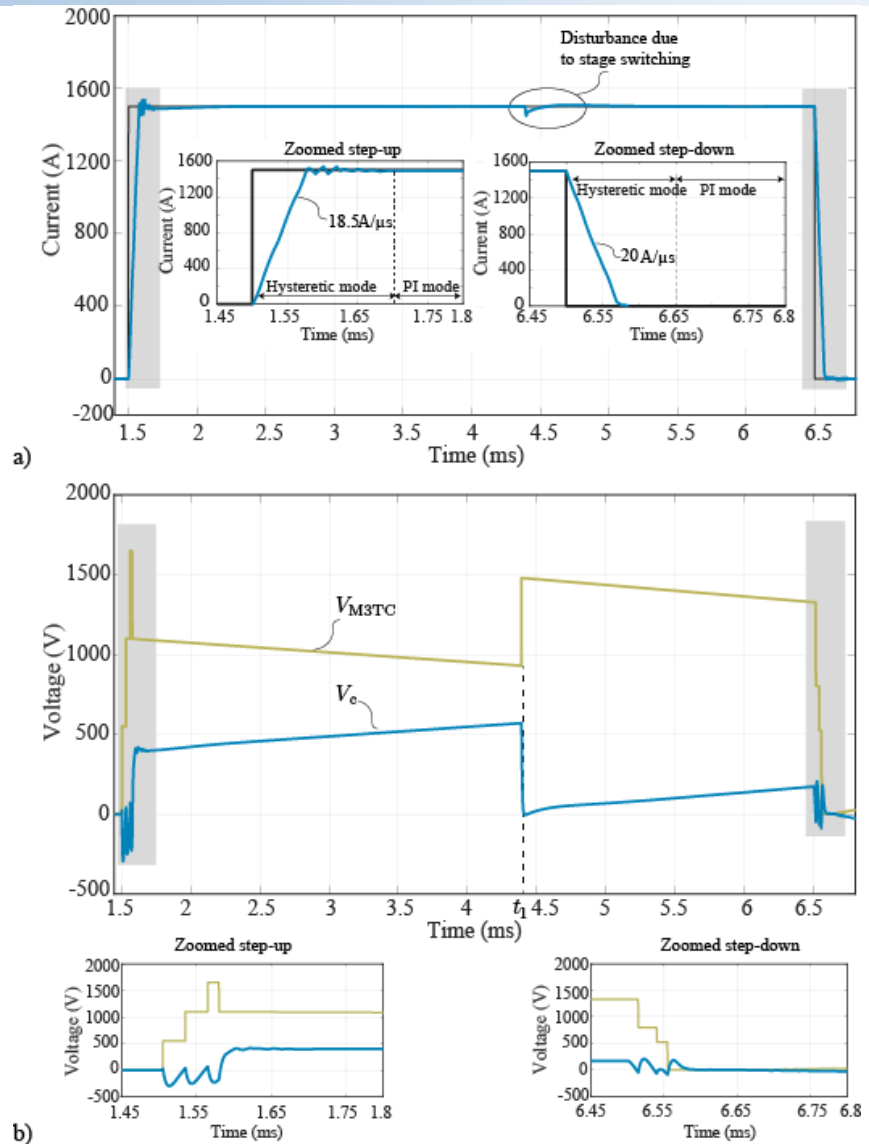
- ✓ Good steady state performance
- ✓ Phase-shifting control → optimal interleaving
- ✓ Design simplicity

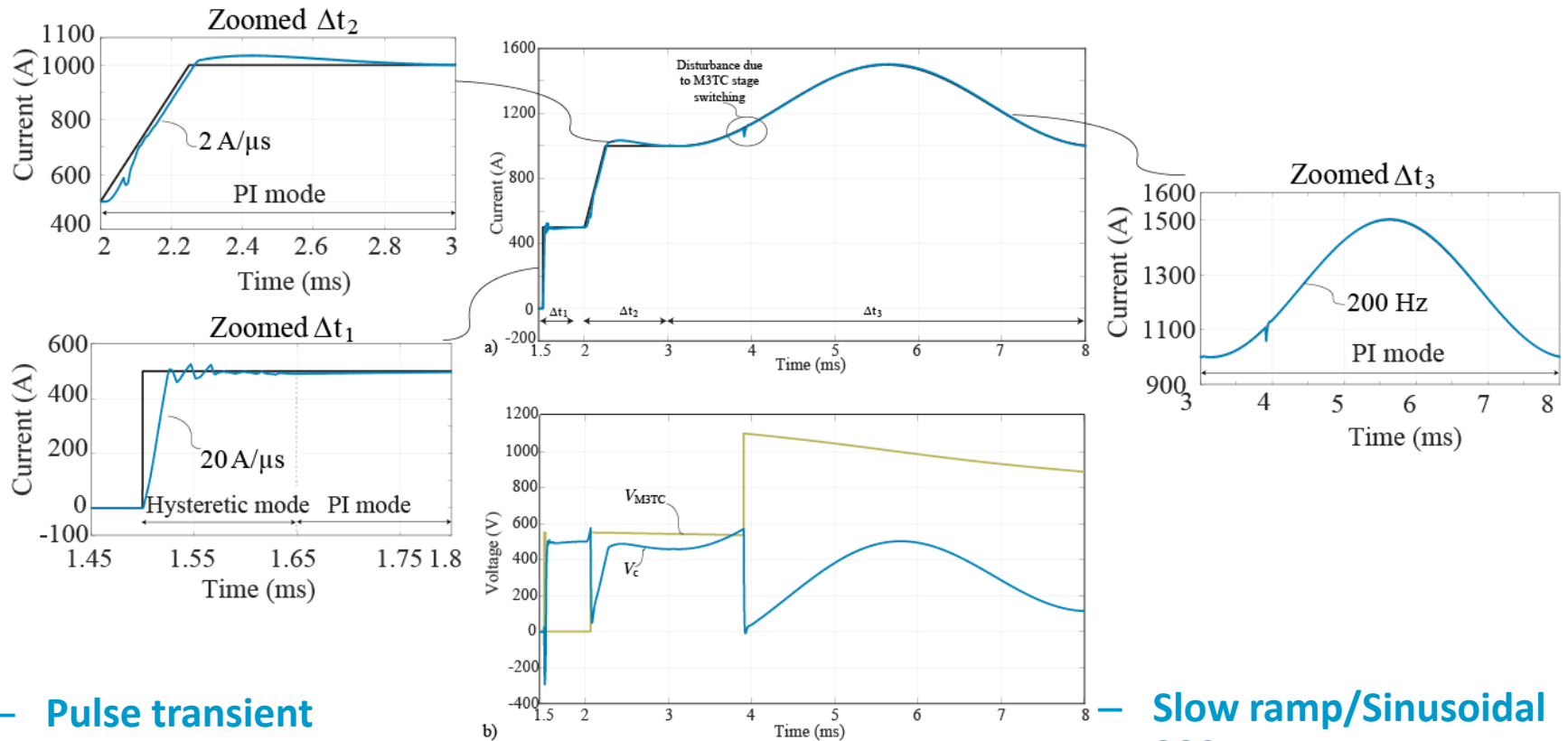
- **M3TC Stage Selection**





- Step-up/down transient
  - Hysteretic mode
  - High current gradient
- Steady State
  - M3TC stage capacitor discharges  $\rightarrow$  additional stage inserted





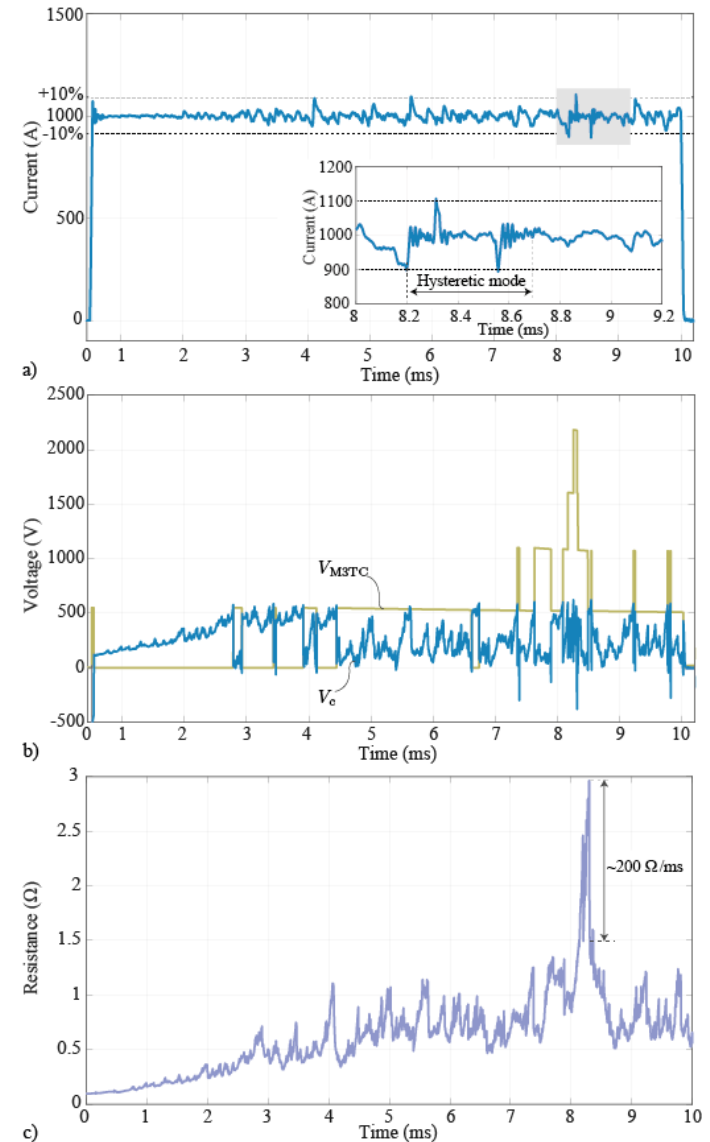
### – Pulse transient

- Hysteretic mode
- Max. achievable current gradient

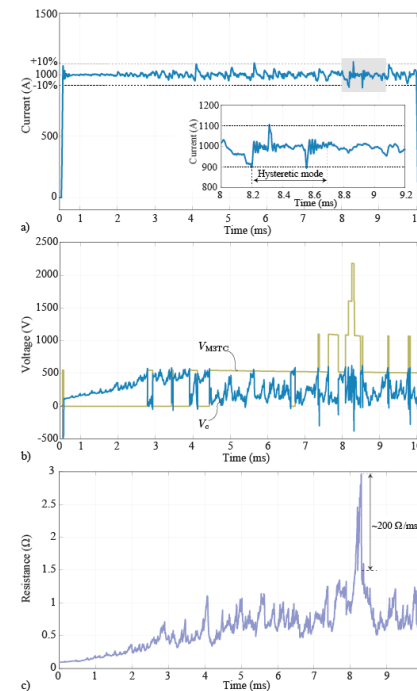
### – Slow ramp/Sinusoidal 200Hz

- PI mode enabled
- Min. ripple during the transient

- Behavioral arc model based on measurements
- Arc voltage stochastically changing
- $>500\text{V}$  in  $2\mu\text{s}$
- Current :  $\pm 10\%$



- Flexible modular arbitrary current source
- High dynamic and robustness
- New advanced controller
- Simulations verify the suitability of the topology



**Thank you for your attention!**

