Investigation of a fast high-repetitive 10-kV SiC-MOSFET switching module

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Outline

- Background/Motivation
- Switching module design
- Experimental setup
- Experimental results
- Summary & Outlook
Introduction – Semiconductor (SC) based pulsed power systems (1)

- Progressive transition from classical gas/(liquid) discharge based towards semiconductor based pulsed power systems (switches & generators)

Switching technology comparison:

SiC power MOSFET

- Very good
- $t_{on} = 20\ \text{ns}$
- $f$ up some MHz
- (almost) infinite
- Worst case $\rightarrow 1$
- $V_{DS} \leq 1200\ \text{V}$
- $I_{D(pulse)} \leq 80\ \text{A}$

Spark gap

- Electrode burn-up
  - $t_r = 7\ \text{ns}$
  - $f \leq 200\ \text{Hz}$
  - $<10^7$
  - $(<10^4)$
- $V \geq 50000\ \text{V}$
- $I_D \geq 10000\ \text{A}$

- Reproducibility and controllability
- Turn on time $t_{on}$
- Pulse repetition frequency $f$
- Lifetime (normal operation)
- Lifetime (excess voltage/current)

- Switching voltage (Series arrangement)
- Switching current (Parallel arrangement)

- Complexity (Synchronous triggering) & Costs
Introduction – Semiconductor (SC) based pulsed power systems (2)

- Our objective:
  Development of SC based fast high voltage (and high current) switching modules & generators for short pulse applications in the defense sector (*Electromagnetic emitter*, electric armor, rail gun, detonators, ...)

- Questions:
  - Operational behavior of SC HV switches & generators on non-resistive/transient loads?
  - SC switch / HV pp system protection?

20-kV module with 1700-V SiC MOSFETs (ABB-ISL circular design)

1st-generation 10-kV module with 1200-V SiC MOSFETs (ISL circular design)
2nd generation 10-kV SiC MOSFET switching module – General design

- General Design:
  - COTS
  - 1200-V SiC MOSFETs: Wolfspeed/CREE C2M0080120D
  - 2-layers with each 5 switches
  - Size: (177 x 95) mm², Layer distance: 13 mm
  - Low-inductive
  - Battery powered
  - Optical galvanic insulation
  - Scalable
2nd generation 10-kV SiC MOSFET switching module – System Protection

- Multiple system protection:
  - 5-MΩ resistors for voltage balancing
  - TVS diodes against transient over-voltages
    - Onset @ 1169 V ⇔ SiC MOSFETs
    - Onset @ 6.6 V ⇔ Opto-receivers
  - External FREDs against voltage reversal (optional)
Experimental setup

- TTL generator
- Control board with 10 opto-transmitter
- Optical cables
- 10-kV SiC MOSFET switching module
- HV power supply
- Load resistor $R_{\text{load}} = 250 \ \Omega$
- Capacitance $C = 45.4 \ \mu\text{F}$
- Charging resistor $R_{\text{ch}} = 4 \ \Omega$
Experimental results (1) – Turn-on & turn-off behavior

Stable turn-on & turn-off behavior
Experimental results (2) – Turn-on times

Comparison turn-on time 2\textsuperscript{nd}-gen. module with 1\textsuperscript{st}-gen. module

Faster current turn-on time: $t_{on} = 37 \text{ ns} \rightarrow 21 \text{ ns} @ V_{SW} = 10 \text{ kV}$
Increased current rise-rate: $\frac{dl}{dt} = 1.0 \text{ kA/\mu s} \rightarrow 1.8 \text{ kA/\mu s}$
Experimental results (3) – Burst mode

Stable 5-MHz burst mode operation (10 cycles)
Summary

- Design, development & testing of fast SiC MOSFET switching module
  - COTS parts
  - System protection
  - $t_{on} = 21 \text{ ns} @ V_{SW} = 10 \text{ kV} & I_D = 38 \text{ A}$
  - Successful burst test: 5 MHz prf, 10 cycles

Outlook

- Speeding-up of turn-on time by means of gate-boosting techniques
- Upscaling to 30-kV switching module class
- Development & testing of multi-stage SC based MARX generator
Thanks for your attention

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