Design and characterization of high-power (S>250kVA) SiC-based current source inverter for photovoltaic applications

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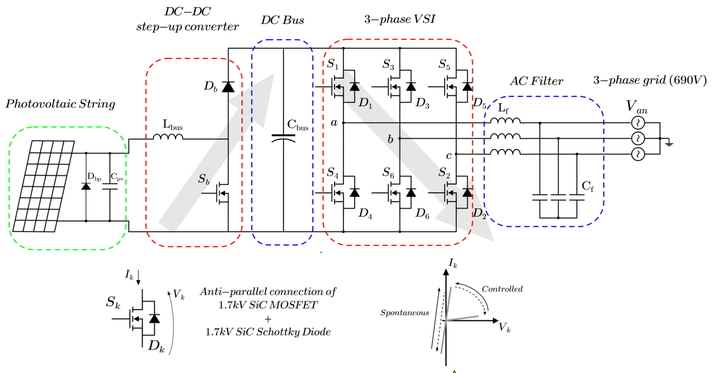
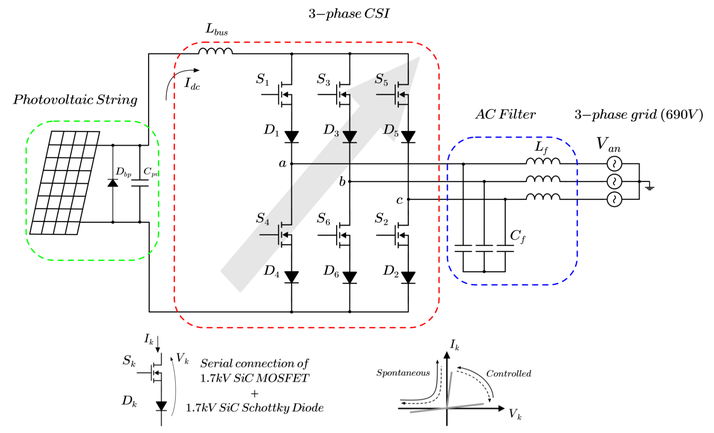
Introduction

- *DC–DC step–up converter + Voltage Source Inverter (VSI)*

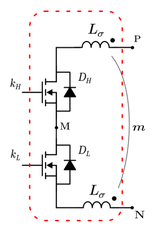


- *Current Source Inverter (CSI)* ★



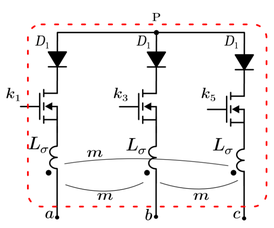
- *Switching Cells in both topologies*

VSI



Leg conf. Module

CSI

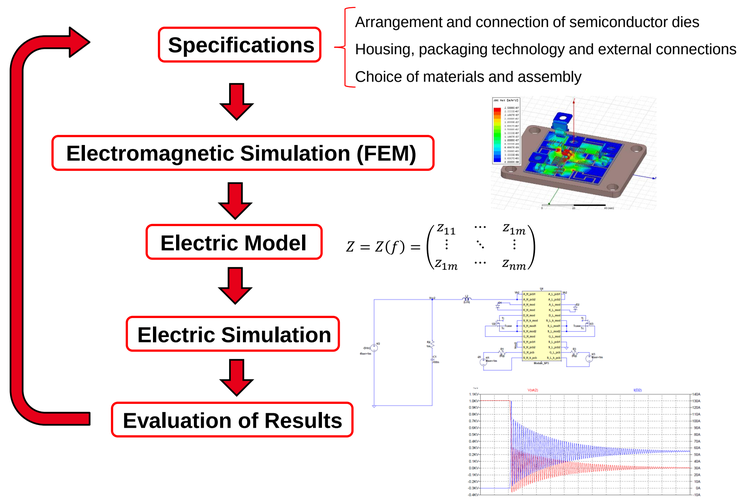


High–side Module

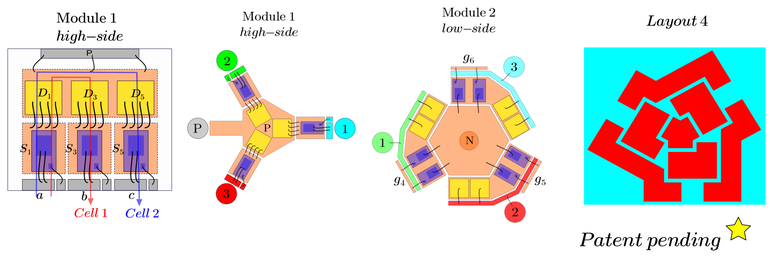
- *Switching occurs separately in High and Low–side*
- *Switching cell alternates between legs P–a,b,c*
- *Balancing and symmetry are required among legs*

CSI Power Module Design [1]

- *Methodology*



- *Insulating Substrate Layout*



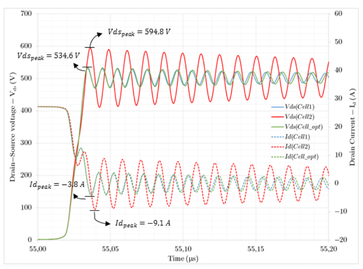
Layout 4

Patent pending ★

- *Results*

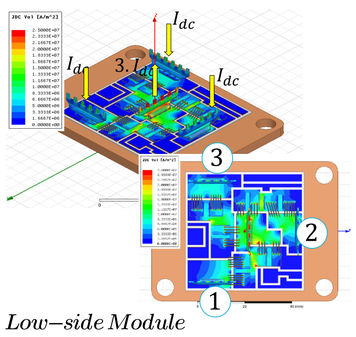
Layout		L_{cell1} (nH)	L_{cell2} (nH)
Layout 1 Unbalanced	Measure	11,95	19,04
	Simul.	12,37	20,13
Layout 4 Balanced	Measure	8,9	
	Simul.	12,65	

Simulated Turn–off Waveforms



@$R_g = 3\Omega, V_{ds} = 500V, I_d = 30A$, MOSFET - C2M0040170D, Diode - CPW51700Z050B

- *CSI Module Design*



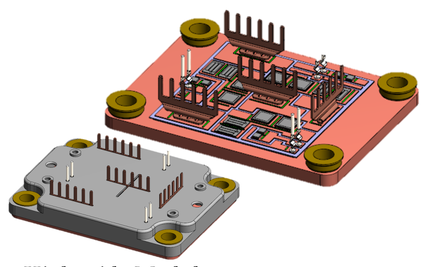
Low–side Module

- *Balanced stray inductances for all switching cells*

Switching Cell	High – side	Low – side
L_{1-2}	16,15	15,56
L_{1-3}	15,23	15,16
L_{2-3}	15,16	15,25

Design rules by Microsemi

- *Final CSI Module*



High–side Module

- *Identical insulating substrate layout for both High and Low–side modules*
- *Balanced stray inductances for all switching cells*
- *Low–profile module (11mm)*
- *Solderable terminals*
- *Footprint 68 X 48 mm*

Switching Losses Measurement

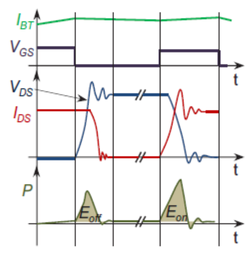
- *Electrical Methods*
- *Calorimetric Methods*

- *Double Pulse Test (DPT) Technique*

- *Fast Measurement time (ctrl of T_j)*
- *Simple test set–up (I and V measurements)*
- *Device's SOA can be monitored*

- *Wide BW current and voltage sensors are required*
- *Current sensor must be introduced in the switching cell*
- *Misalignment between V and I probes*

Typical Waveforms

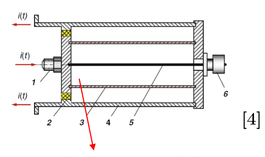


[2]

Current Measurement Techniques [3]

- *Coaxial Shunt*

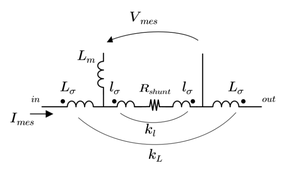
- *Construction*



[4]

Magnetic field cancellation inside the inner chamber

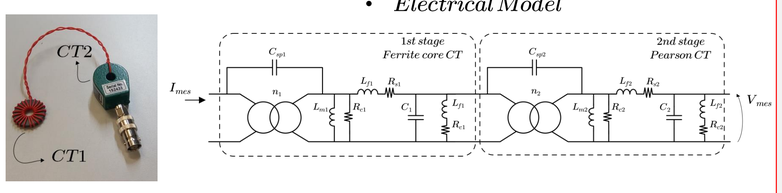
- *Electrical Model*



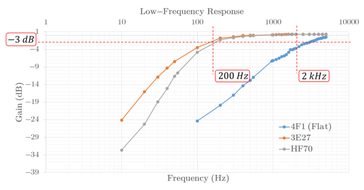
- $R_{shunt} = 0{,}0997\ \Omega$
- $BW = 1{,}2\ GHz$

- *Double–stage Current Transformer (DSCT)* ★

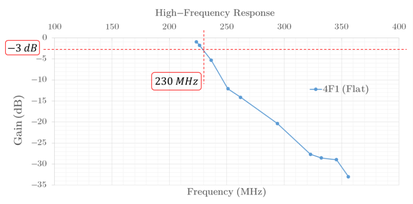
- *Electrical Model*



Low–Frequency Response

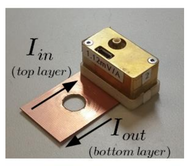


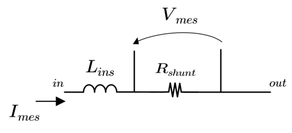
High–Frequency Response



- *Active Shunt*

- *Electrical Model*

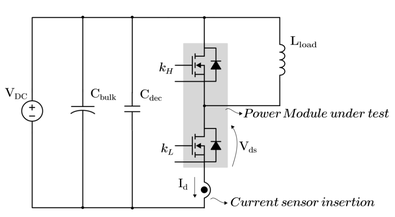




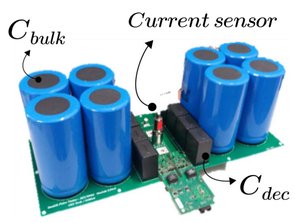
$70\ kHz < BW < 400\ MHz$

- *Switching Waveforms Comparison*

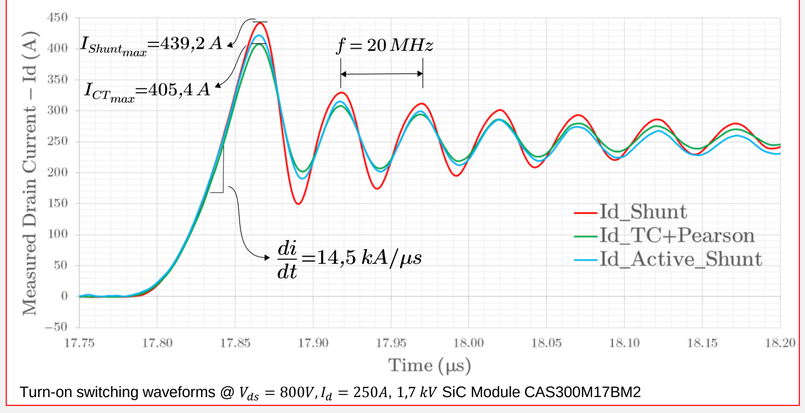
- *DPT Circuit*



- *Prototype*



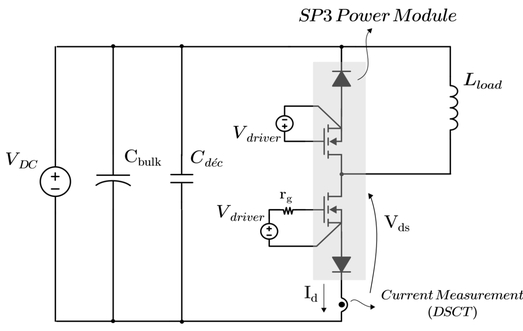
Current waveform at Turn–on



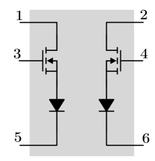
Turn–on switching waveforms @ $V_{ds} = 800V, I_d = 250A$, 1,7 kV SiC Module CAS300M17BM2

Switching Characterization - $E_{sw}\ (V_{ds}, T_j, R_g)$

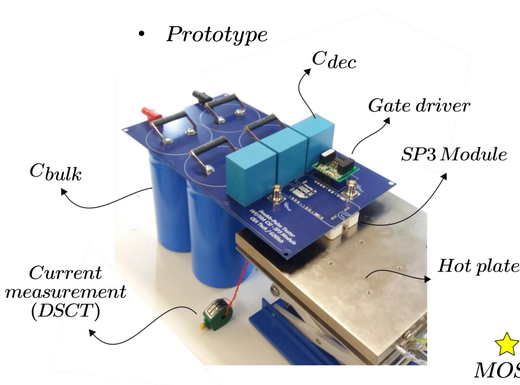
- *Modified DPT Circuit*



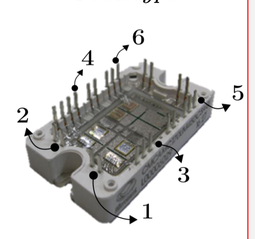
- *Full–SiC 1,7 kV Module*



- *Prototype*



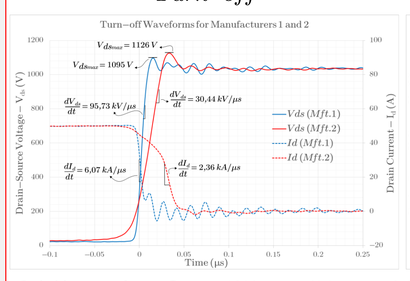
- *SP3 Module Prototype*



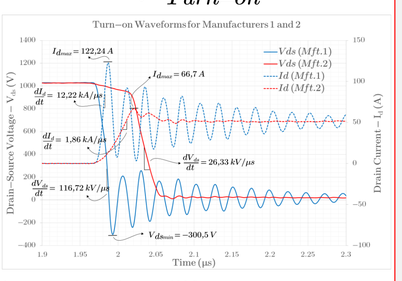
★ *2 combinations of MOSFET+series diode were investigated → 2 different manufacturers*

- *Switching Waveforms*

- *Turn–off*

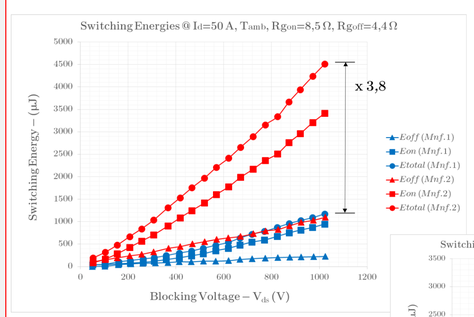


- *Turn–on*



Switching waveforms @ $V_{ds} = 1000V, I_d = 50A$, $R_{gon} = 2{,}5$, $R_{goff} = 1{,}4$ and $T_j = 150°C$

- *Switching Energies*

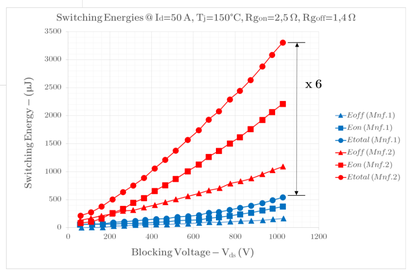


- *Non–negligible difference between E_{sw} from mnf. 1 and 2*

↓

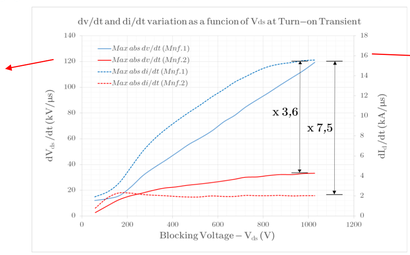
Why?

→ *2 key factors in terms of E_{sw} : R_g and C_{rss} (cf. Table 1)*



- *Trade–off between E_{sw} and EMI aspects*

$\frac{dv}{dt}_{max} = 120kV/\mu s$



$\frac{di}{dt}_{max} = 16\ kA/\mu s$

Table 1 – MOSFET parameters for Manufacturers 1 and 2.

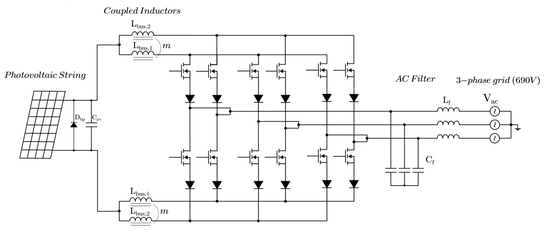
Parameter	V_{dsMAX}	I_d (A)	$R_{DS(on)}$ (mΩ)	$R_{g(int)}$ (Ω)	C_{iss} (pF)	C_{oss} (pF)	C_{rss} (pF)	Q_g (nC)
Manufacturer 1	1700	48	90	1,3	3672	171	6,7	188
Manufacturer 2	1700	58	85	14,9	3606	127	34	198

Conclusion and Perspectives

- *A full–SiC Power Module suitable for CSI applications was designed*
- *Several current sensing techniques were investigated → the DSCT shows the best performances (adopted solution for future works)*
- *1,7 kV switching characterization was carried out and semiconductor dies from mnf.1 were chosen*

→ *Experimental validation of the presented CSI Module (August 2017)*

→ *Towards a High–power multilevel Current Source Inverter:*



References

[1] Alves Rodrigues, Luis Gabriel et al. "*Switching Cell Design Optimization of SiC-based Power Modules for Current Source Inverter Applications*" - EPE 2017.

[2] Brandelero, J. C. "Conception et réalisation d'un convertisseur multicellulaire DC/DC isolé pour application aéronautique" PhD Thesis, Toulouse (2015).

[3] Alves Rodrigues, Luis Gabriel et al. "Characterization of 1.7 kV SiC MOSFET Modules for Medium/High Power Current Source Inverter in Photovoltaic Applications" – PCIM 2017.

[4] SCHON, Klaus. High impulse voltage and current measurement techniques. Springer, Berlin, 2013.