REINHOLD ENVIRONMENTAL Ltd.

2018 APC & Wastewater Round Table & Expo Presentation

July 23 & 24, 2018 in Lexington, KY / Hosted by East Kentucky Power Coop

ESP operation; Aspects on Dynamic Boiler Load Variations and Highly Efficient Power Supplies

Reinhold Environmental

Round Table 2018

Lexington, KY, July 23rd, 2018

GE Power

Per Ranstad

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Topics

Aspects on Dynamic Boiler Load Variations

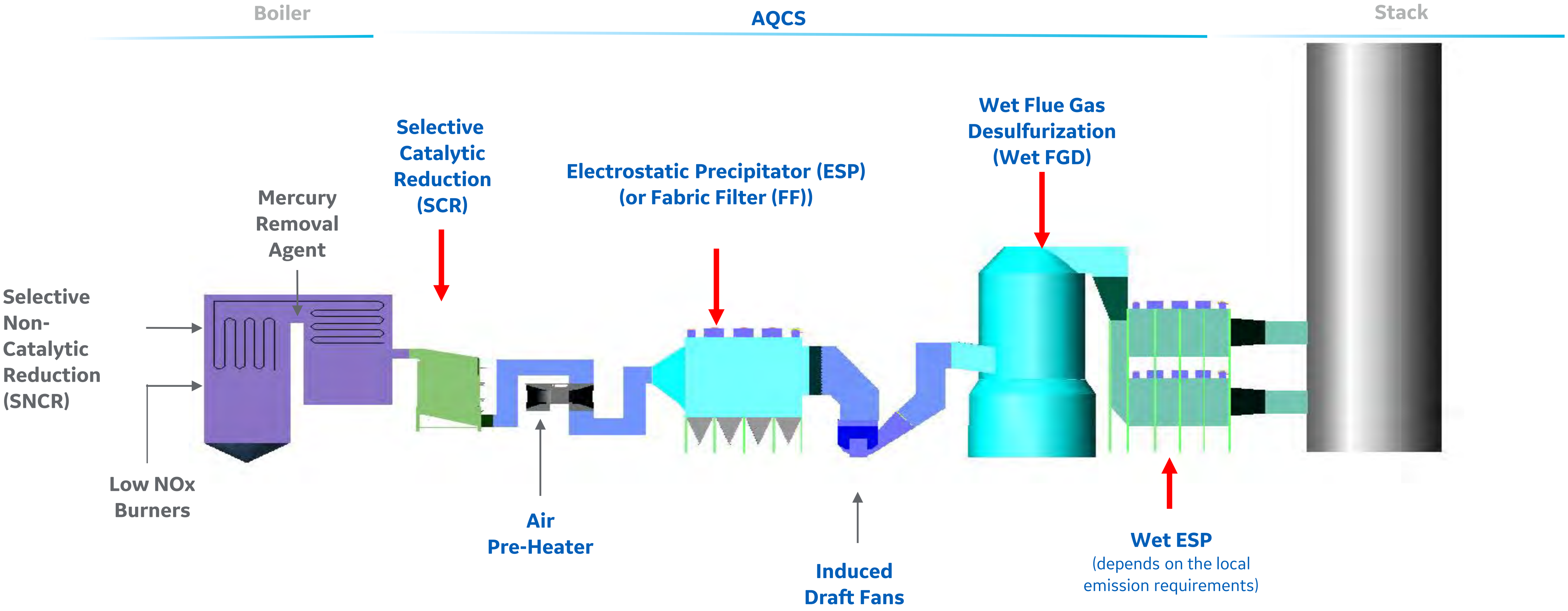
- General
- Effects on gas velocity in duct
- Dust build up, stickiness
- High voltage isolation system
- Gas distributions, electrical effects
- Conclusion1

Highly efficient power supply

- Wide Band Gap power semiconductors
- Application/circuit
- Motivation
- SiC Power Devices
- Results
- Conclusion2

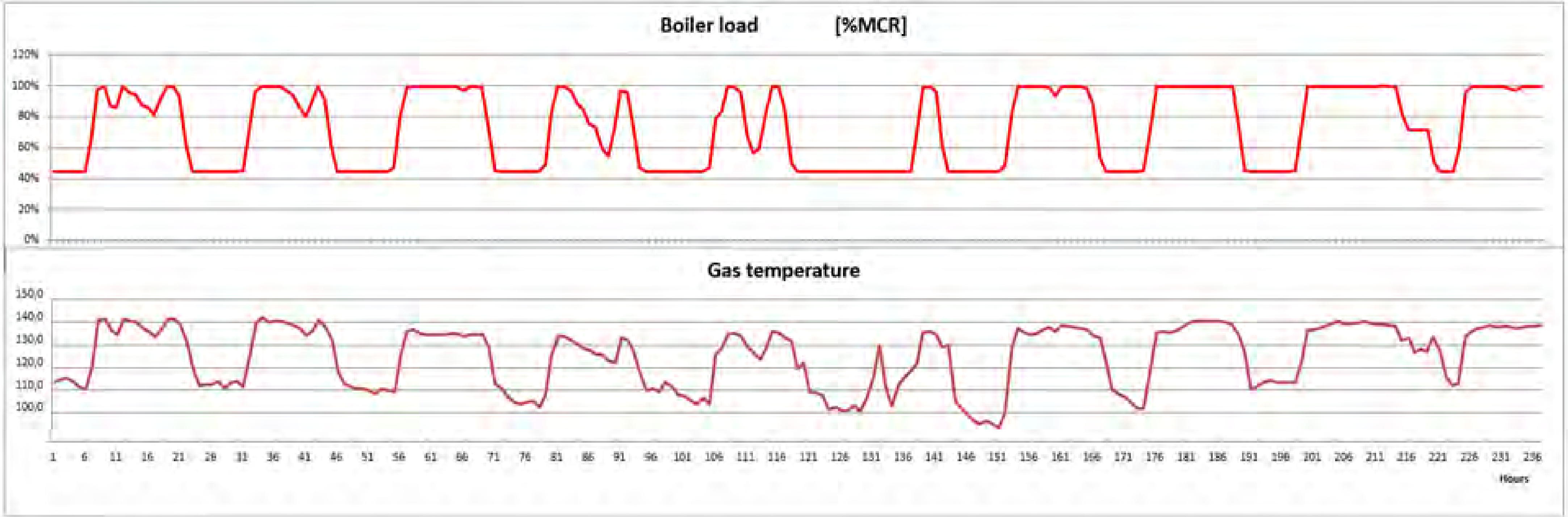
Aspects on Dynamic Boiler Load Variations

GENERAL



Dynamic Boiler Load Variations

Example of 500 MW coal fired boiler operation, load trend.



Relative boiler load (%) and ESP inlet gas temperature (°C) vs time (h).

Aspects on Dynamic Boiler Load Variations

Currently coal fired boilers installations are being upgraded:

- to be able to operate at further reduced minimum loads
  extended low load operation from 65% to 35%
- with installation for reduction NOx emission - Selective Catalytic Reactor (SCR),

Consequences of low load operation:

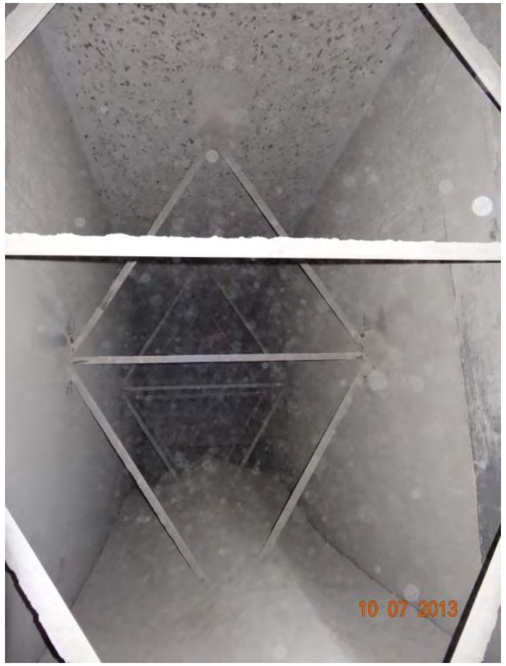
- lower quantities of combustion gases are produced,
- SCR - ammonia slip in combustion gases,
- SCR catalyst - affects conversion rate of SO_2 to SO_3 (0.5 - 1%)
- Higher SO_3 in flue gases and ammonia slip increases temperature off Acid Dew Point (tADP),
- Often flue gas temperature before Electrostatic Precipitator (ESP) is close to or lower than tADP,
- Flue gas cleaning system – gas ducts, ESP typically are delivered with size for maximum volume gas flow.

Effects of lower gas velocity in duct

Dust build up in horizontal flue gas duct

Low boiler load reduces gas velocity:

- Low flow velocity in gas ducts before ESP,
- Risk of dust build up (deposition) in gas ducts
- Risk of collapse, structure
- Risk to format solid material
- Changes in gas distribution quality
- Dynamic overload of ESP at ramp up of load



10% of cross section

40% of cross section

Effects of lower gas velocity in duct

Dust build up at duct bend and at ESP inlet

At low volume flow of combustion gases

- Duct bend gives higher velocity at periphery
- Dust deposits at inner wall
- Lower velocities at ESP inlet due to bigger cross section
- Dust depositions at inlet
- Risk of collapse, structure
- Risk to format solid material
- Changes in gas distribution quality
- Dynamic overload of ESP at ramp up of load

Duct bend

ESP inlet

Dust build up, stickiness

Low temperature, risk of moisture condensation

Low flue gas temperature means risk of moisture condensation in the ESP:

- wet dust layers
- dust build up on electrodes, rapping
- dust bridges in bottom hoppers are often created,
- a high level of ash in bottom hopper and difficulties with ash dislodging,
- problems with pneumatic ash handling systems.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Roof beam

Inlet screen partially blocked

Dust build up, stickiness

Low temperature, risk of moisture condensation

Hopper, typical problems:

- wet dust, sticky
- dust bridges in bottom hoppers are often created,
- a high level of ash in bottom hopper and difficulties with ash dislodging
- shorted electrical system
- problems with ash handling systems.

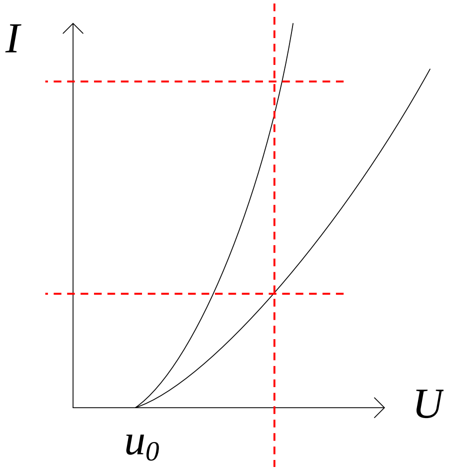
Pyramid bottom hopper and dust bridges– high level of ash may short circuit the bus section

Gas distribution, electrical effects

Analysis:

- Condensation at areas with lower velocity
- Dust build up on plate, wet dust
- Uneven current distribution due to dust build up

U-I characteristic

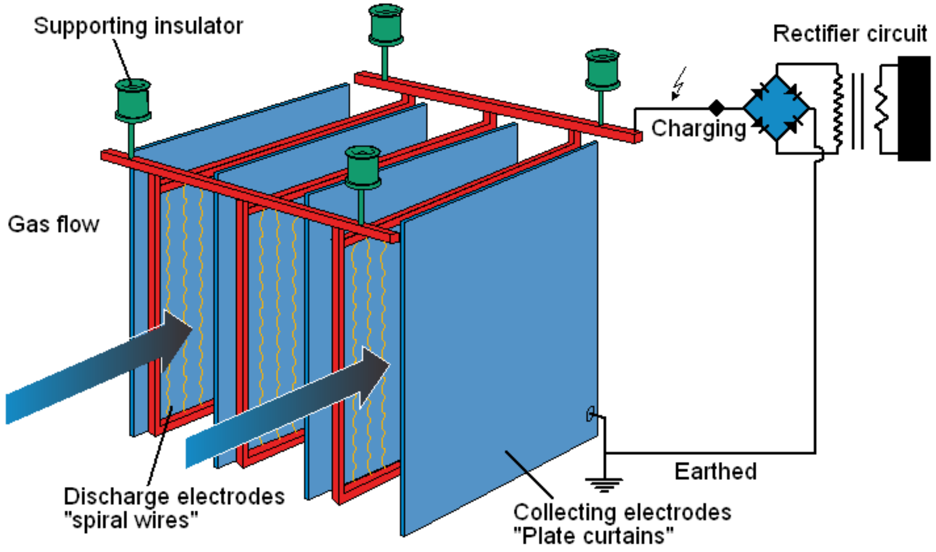


Thick dust layer (sticky) at upper part of collecting plate. Lower velocity.

Thin dust layer at lower part of collecting plate. Higher velocity.

High voltage isolation system

Support insulators



Supports mechanical load of emitting electrode system and provide electrical isolation to ESP roof:

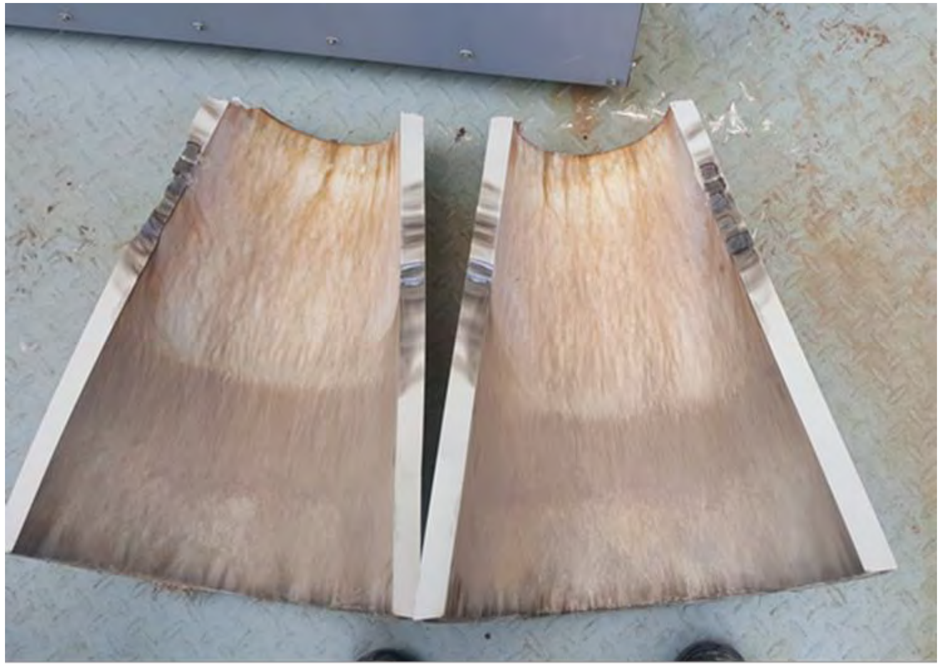
- Electrical heating or air flushing
- Top plate carries the load of emitting system
- Actual case shows mechanical crack
- Electrical operation disturbed (sparking)

High voltage isolation system

Support insulators breakage, condensation

Broken support insulator:

- Dust on inner surface of insulator
- Condensation in dust layer
- Lower part of insulator is less stressed, electrically
- Upper part is highly stressed, PD and treeing
- Finally insulator breaks
- Insufficient heating and lack of thermal isolation



Aspects on Dynamic Boiler Load Variations

Conclusions 1

Low load operation may cause changes:

- Dust deposit in ducts and bus sections
- Flue gas properties (acid dew point)
- Fly ash properties (stickiness)

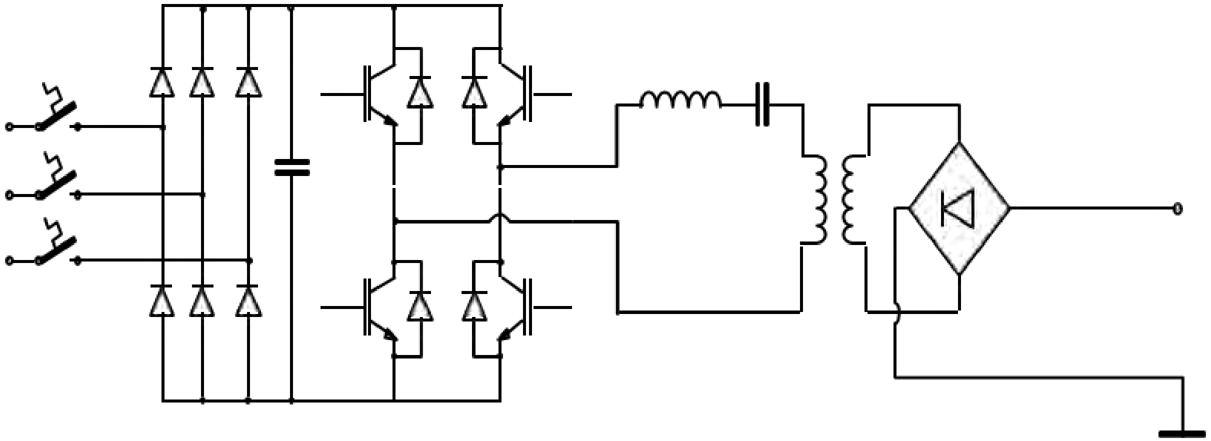
Resulting in negative impacts on:

- Gas flow distribution
- Electrical field

Highly Efficient Power Supplies

New semiconductor materials enables:

- Higher efficiency
  - Lower parasitic losses
- Higher power density
  - Less material used
- Allows higher ambient temperatures
- Improved ESP control
  - Faster response
  - Pulsing



Acknowledgements

(‘Highly Efficient Power Supplies’)

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- KiC Innoenergy
- SiC Power Center

Contributors:
- Florian Giezendanner, GE
- Jörgen Linner, GE
- Diane Sadik, KTH

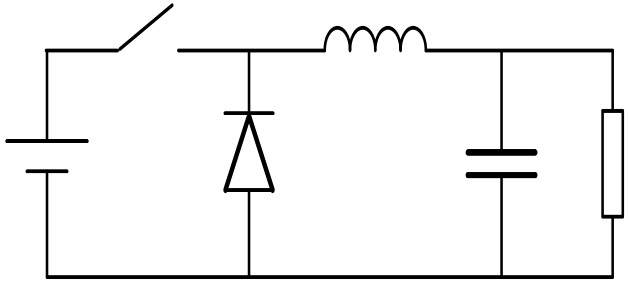
Wide Band Gap materials for Power Semiconductors

Properties	Si	GaAs	6H-SiC	4H-SiC	GaN	Diamond
Bandgap energy, E_g, (eV)	1.12	1.43	2.9	3.25	3.4	5.5
Critical field strength, E_B,(MV/cm)	0.25	0.4	2.5	2.5	2.0	10
Electron mobility, μ_n,(cm^2/Vs)	1500	6500	400	800	900	2000
Thermal conductivity, λ, (W/cm K)	1.5	0.5	4.9	4.9	1.3	20
Dielectric constant, ε	12	13	9.7	9.7	10	5.7
Figure of merit vs Si FOM $=\lambda\cdot\varepsilon\cdot\mu_n\cdot E_B^3$	1	6.4	700	1400	220	540 000

***Expected impact from WBG power devices*:**

- Reduced conduction losses
- Higher switching speed
- Higher temp. rating
- Higher component cost

Power Converter



Power Module

Discrete device

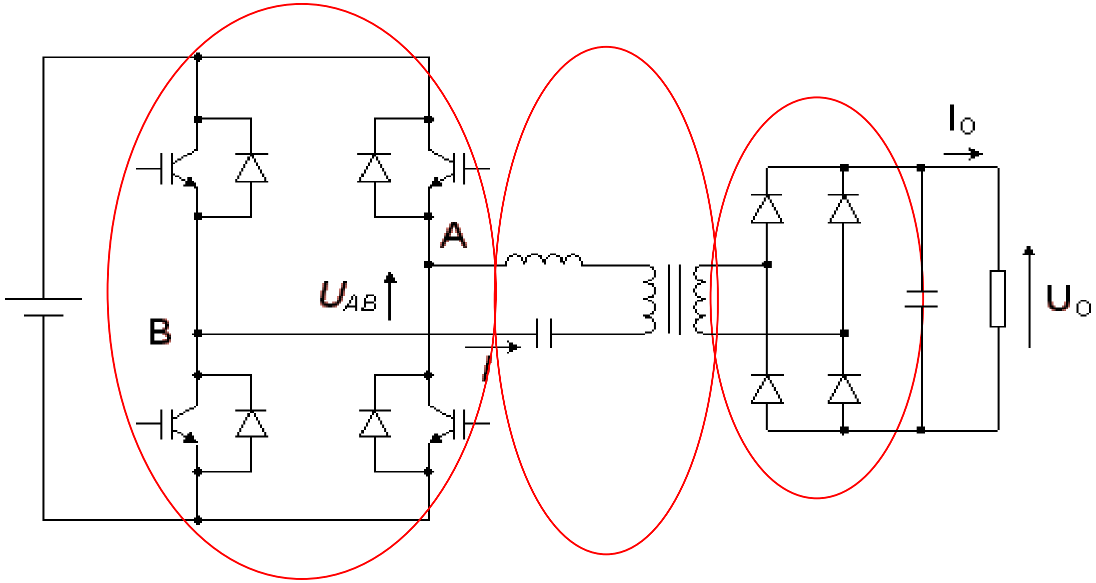
Power Supply System

Potential impact from SiC power components

- **Improved energy efficiency**
  - Improved power density
    - Cooling system
  - Reduced operational cost
    - Higher efficiency

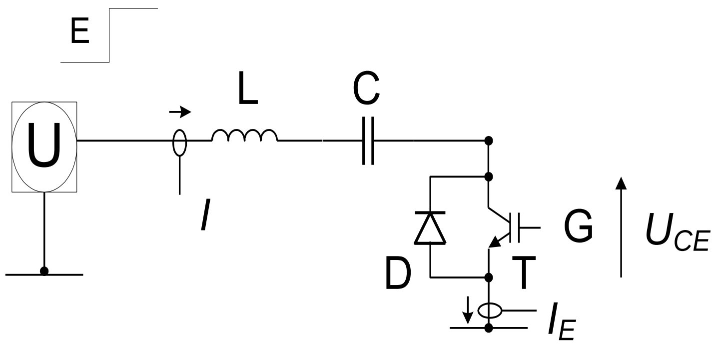
- **Reduced switching losses**
  - Higher switching frequency
    - f_s 100 - 200 kHz
  - Improved power density
    - Reduced size (cost) of reactive elements

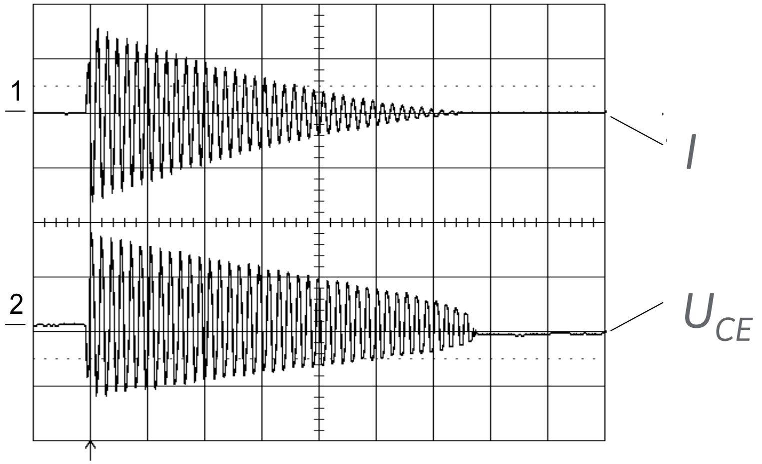
- **Higher junction temperature operation**
  - Allows higher ambient temp



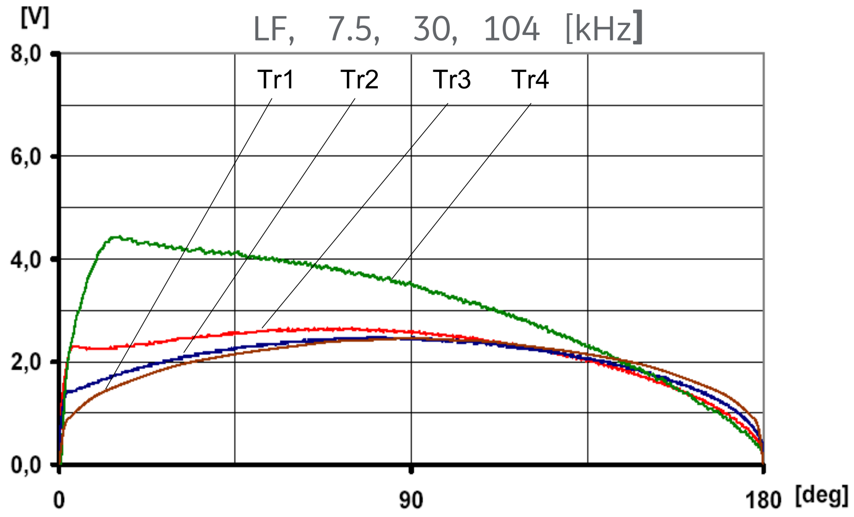
Si IGBT , Dynamic effects

On-state voltage and tail-charge

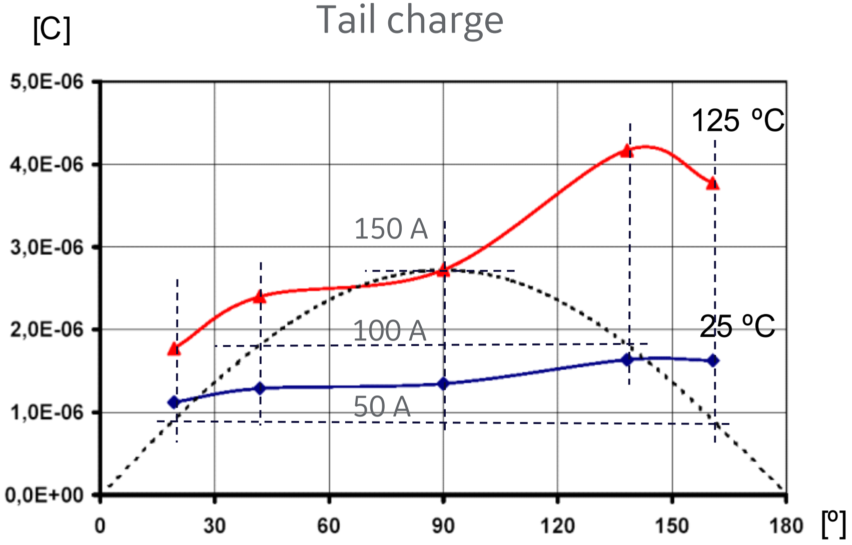




On-state voltage, î=150 A, 25 C°



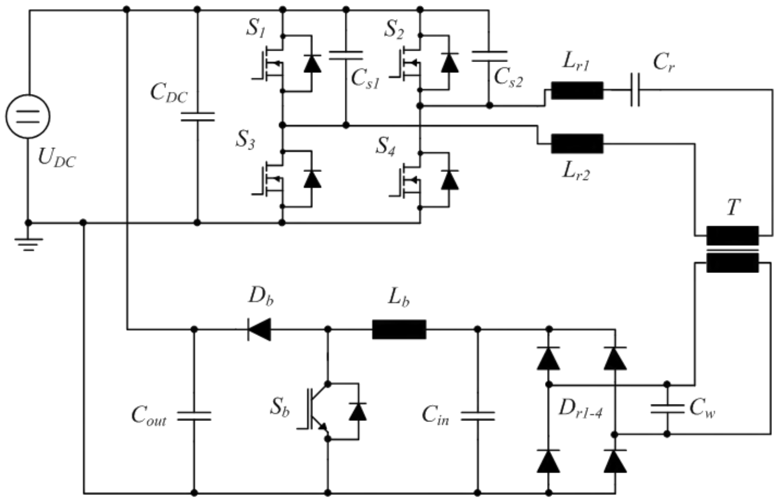
Tail charge



Evaluation of SiC switches

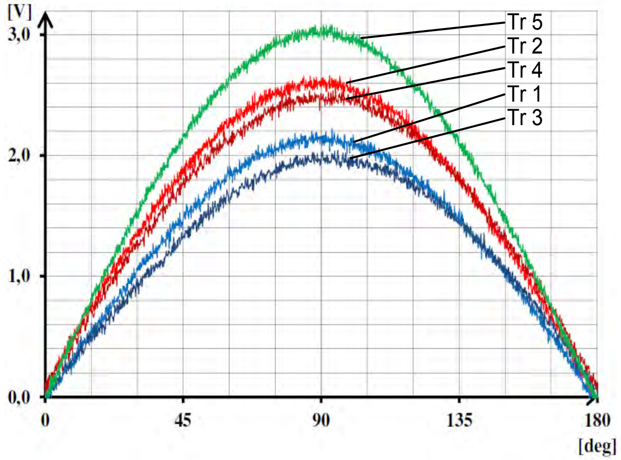
Losses, on-state and system

Test system, 60 kW



No dynamic effects observed, 200 kHz

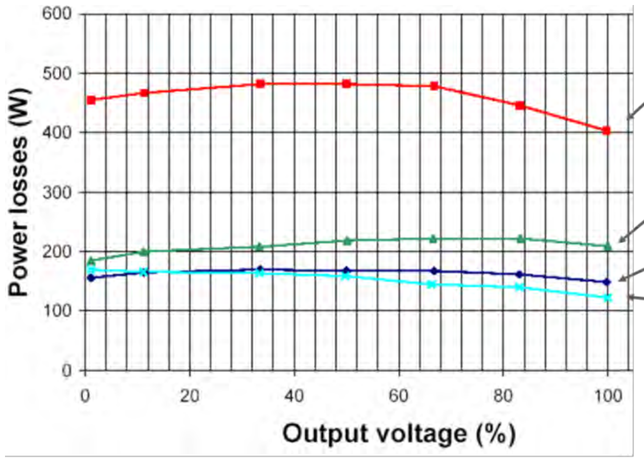
Losses reduce by 2/3 in system, 25-30 kHz



On-state voltage, î=150 A

T_J; 25, 125°C, f ; 30, 200 kHz

Inverter losses



(#1) Si-IGBT
512 mm²(100 %)

(#2) SiC-MOSFET
101 mm²(20 %)

(#3) SiC-JFET
54 mm²(11 %)

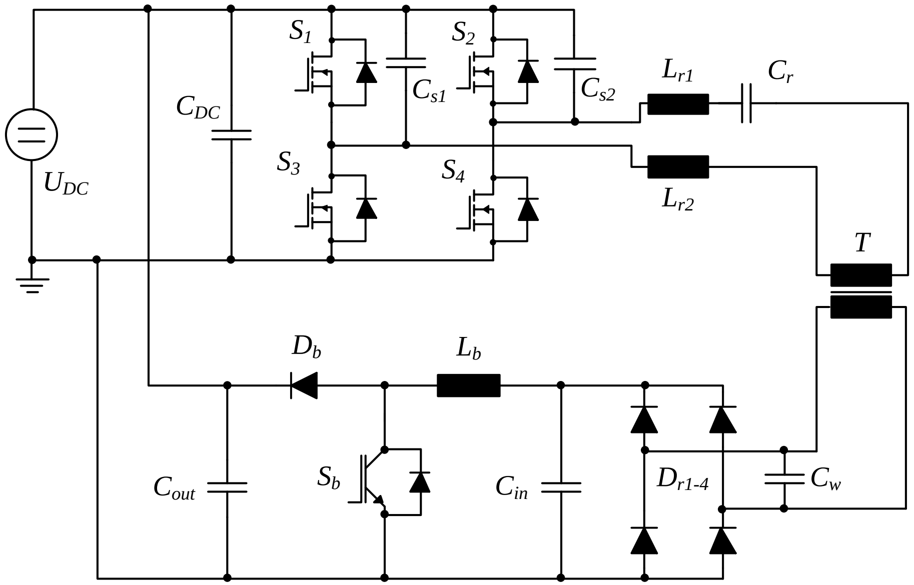
(#4) SiC-BJT*
73 mm²(14 %)

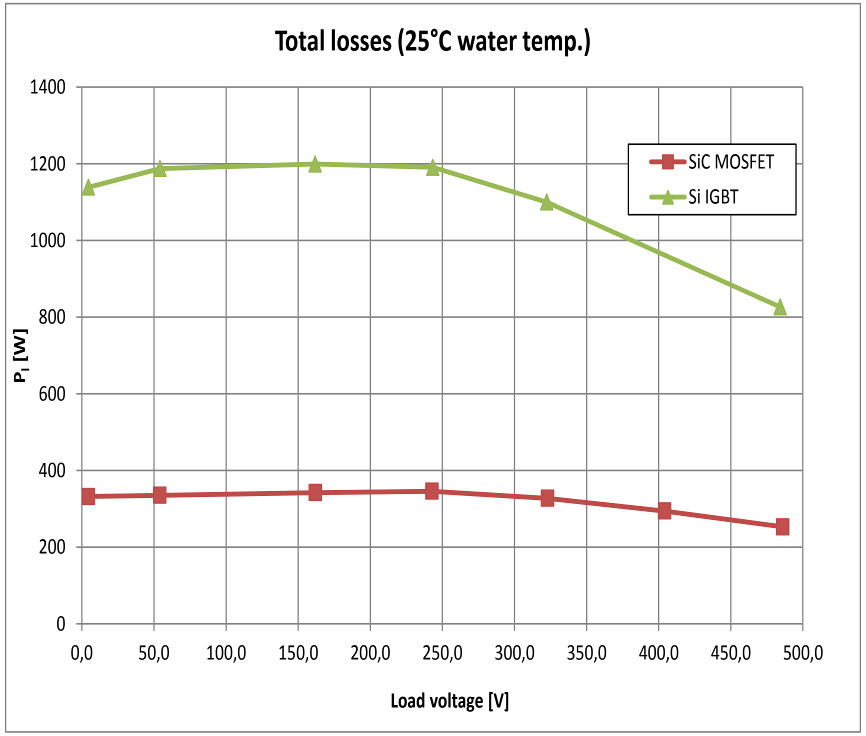
I_O 100 A
U_O 0-360 V
f_s 25-30 kHz
U_{DC} 400 V
T_J ~50 °C

Note: Gen 1 MOSFET
Significant improvments
in present generations.

SiC MOSFET Module vs Si IGBT, 62 mm package

Measured inverter losses vs. load voltage, I_O=120 A

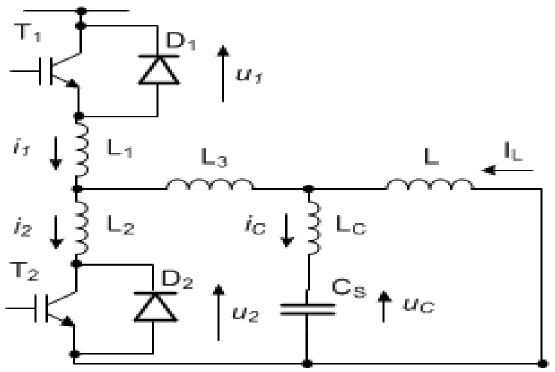


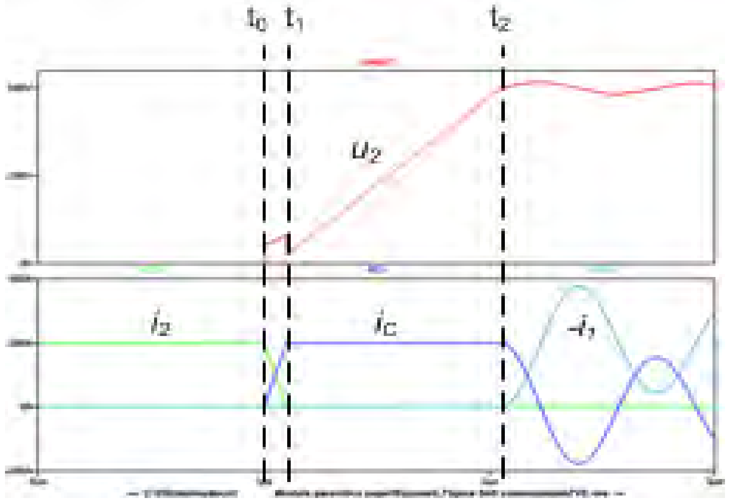


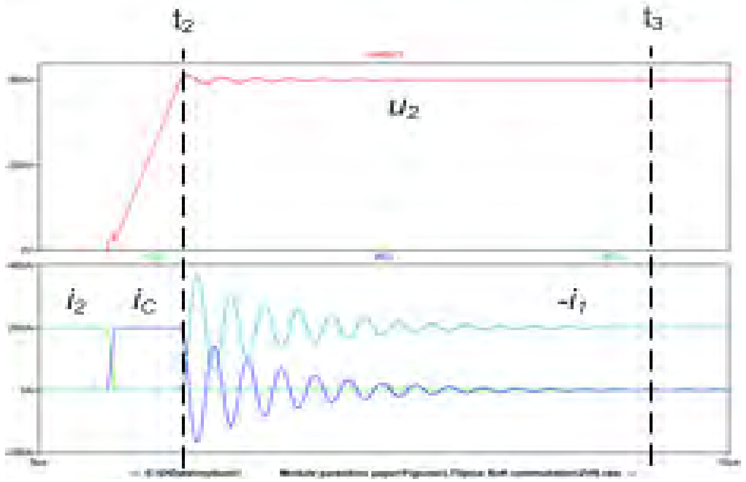
- Approx. 30% of the Si IGBT losses
- $R'_L = P_L / I^2 * R_{DSon} \approx 1{,}5 - 2$ (25-30 kHz)

Soft-switching , ZVS, using capacitive snubber

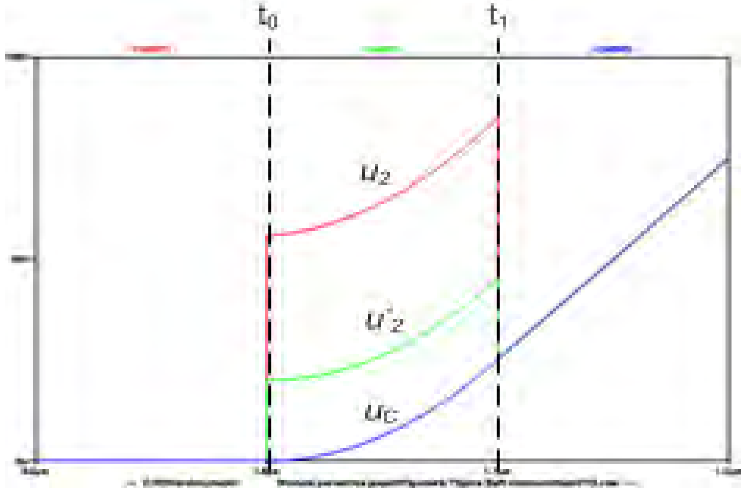
Effect of parasitic inductance in commutation loop, simulations







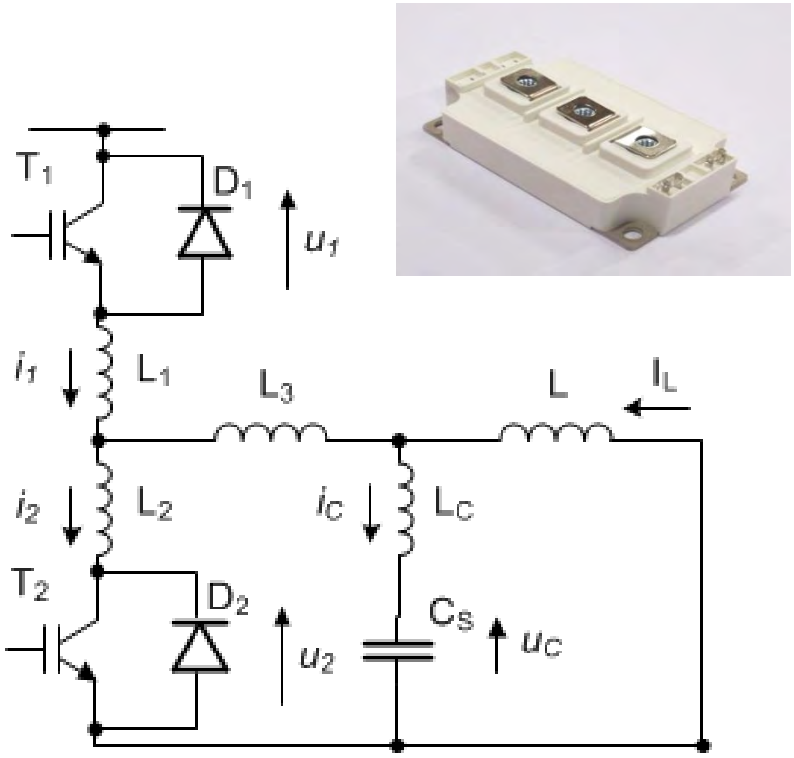
$W_{Ind} = ½ L*i^{2}_{OFF}$.

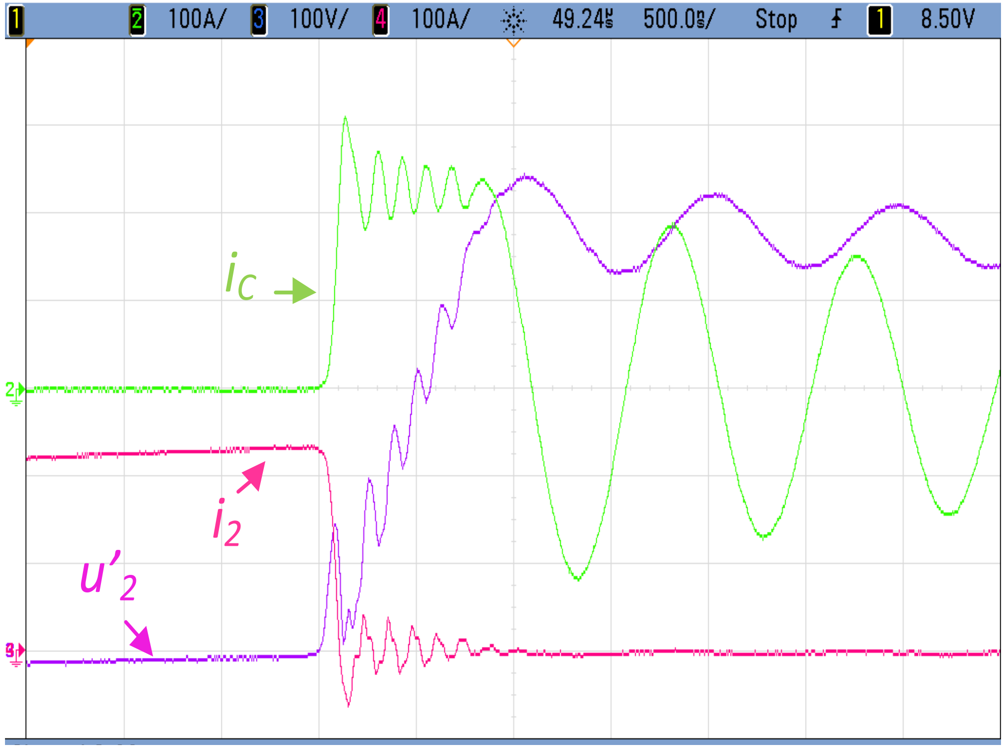


$W_{Ind} = ½ L*i^{2}_{OFF}$.

Soft-switching , ZVS, using capacitive snubber

Measurements, effects of parasitic inductance





Parasitic Inductances

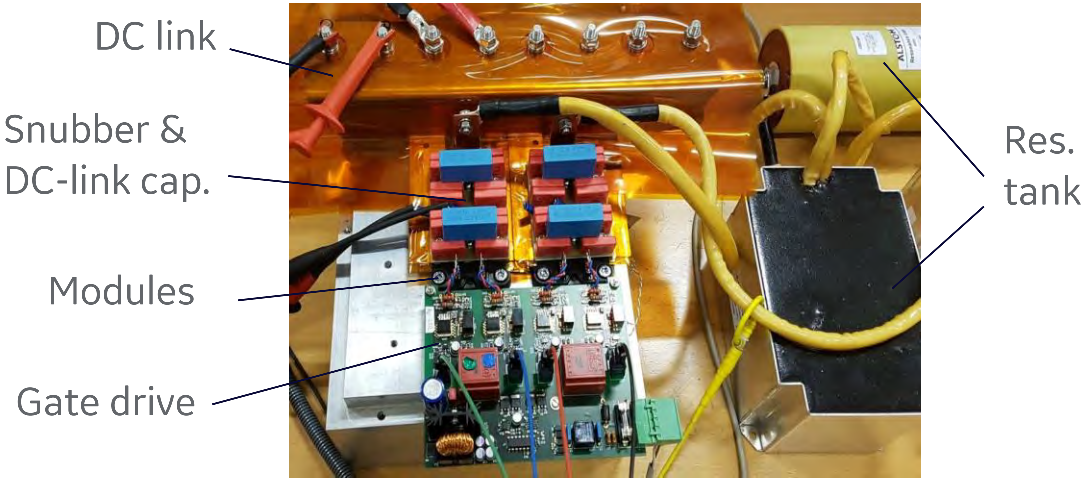
Module comparison - Snubber loop inductance

62 mm - Wolfspeed CAS300M12BM2

f_{osc} = 1.65 MHz, $C_{snubber}$ = 180 nF
$\rightarrow$ **$L_{loop} \approx$ 52 nH**

Wolfspeed CAS325M12HM2

f_{osc} = 6.3 MHz, $C_{snubber}$ = 66 nF
$\rightarrow$ **$L_{loop} \approx$ 10 nH**



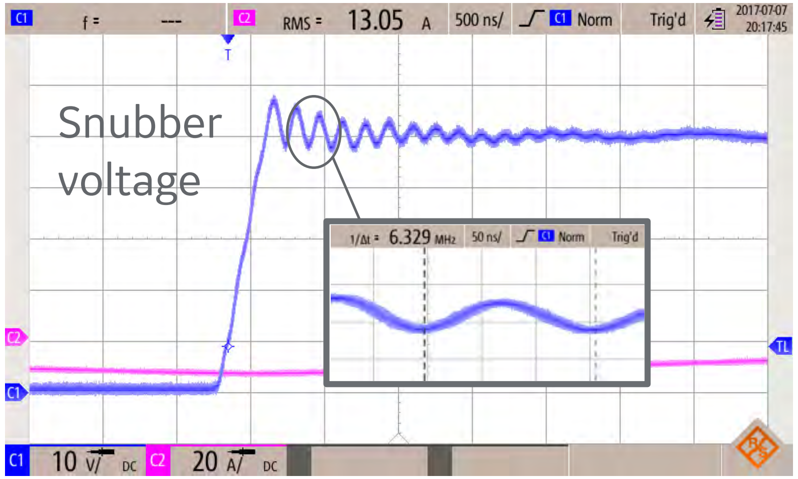
DC link

Snubber &
DC-link cap.

Modules

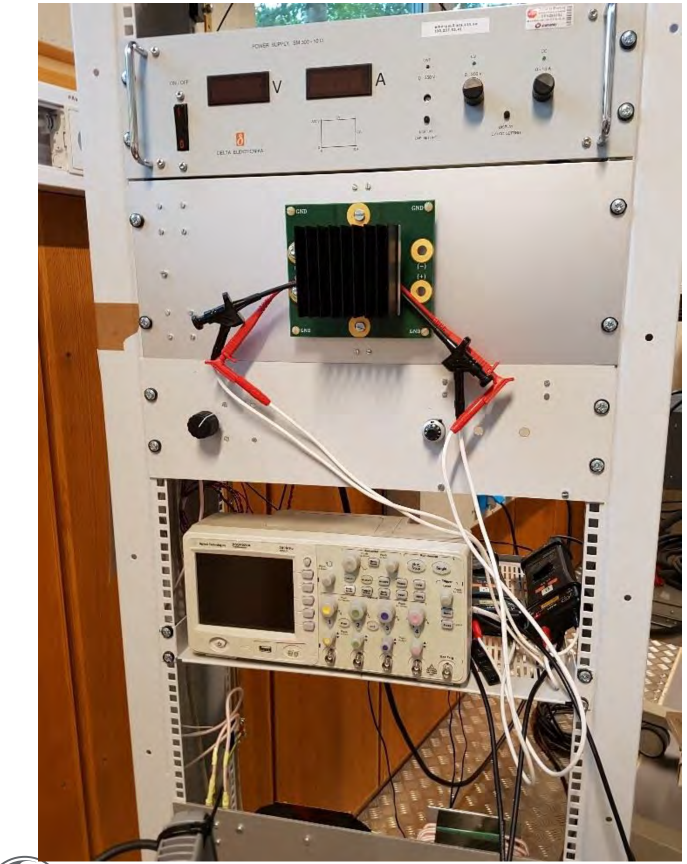
Gate drive

Res.
tank



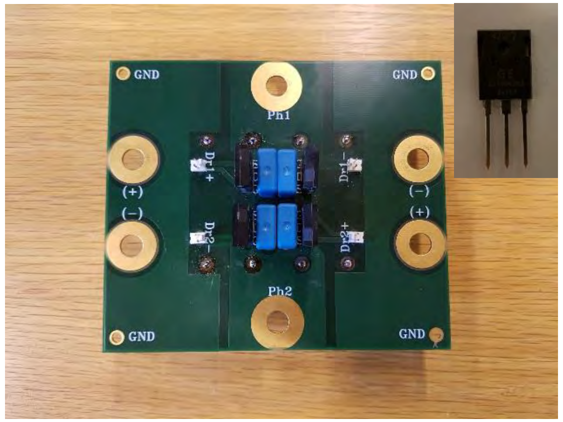
Parasitic Inductances

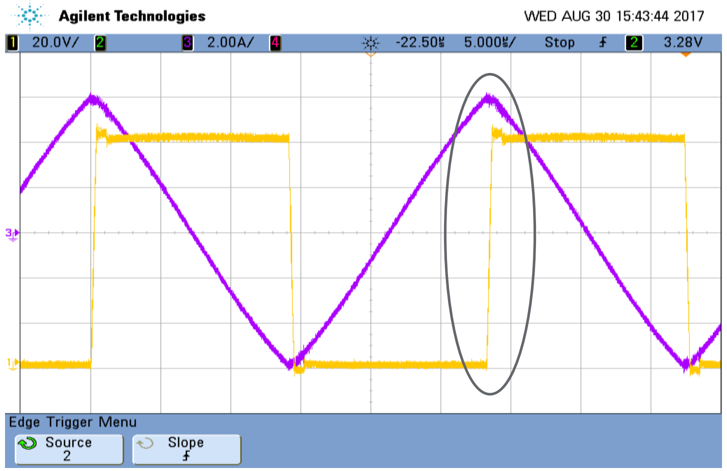
Discrete implementatation, TO247 - Snubber loop inductance

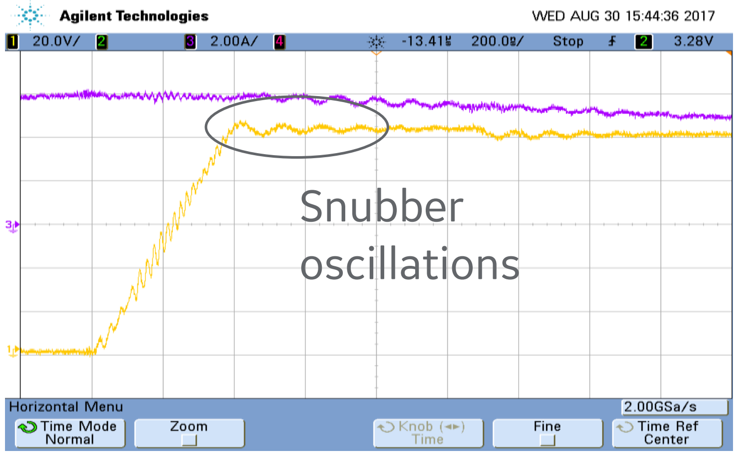


GE12009000AD - TO247

f_{osc} = 9.0 MHz, $C_{snubber}$ = 20 nF
$\rightarrow$ **L_{loop} ≈ 16 nH**



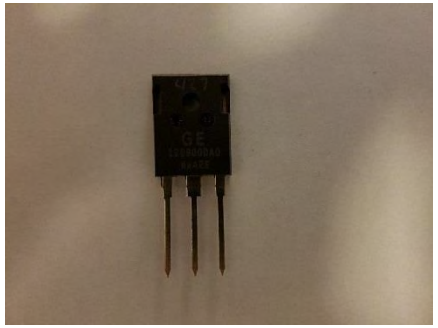




Snubber oscillations

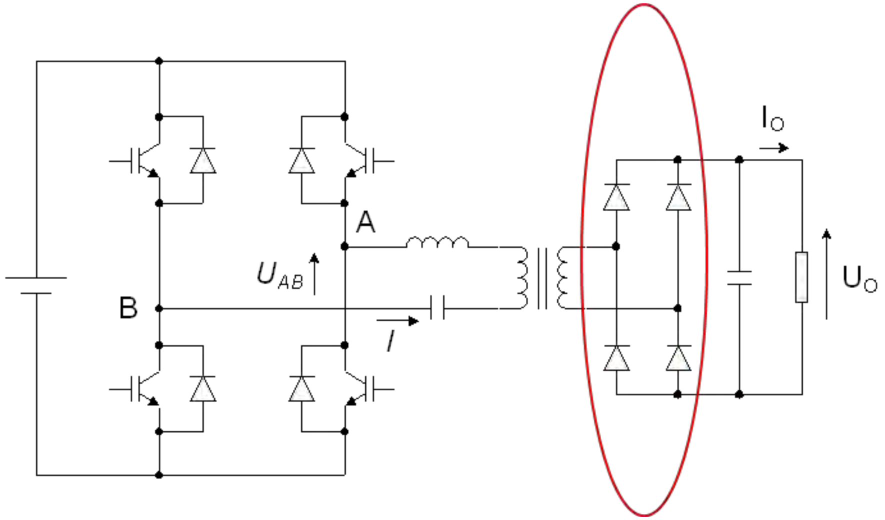
Parasitic Inductances

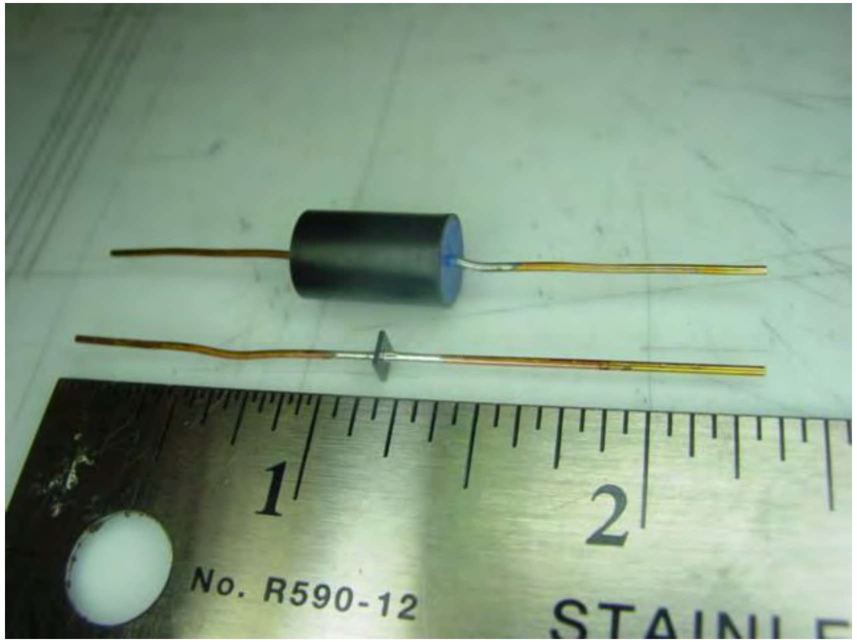
Comparison of packages, results normalized to R_{DSon}

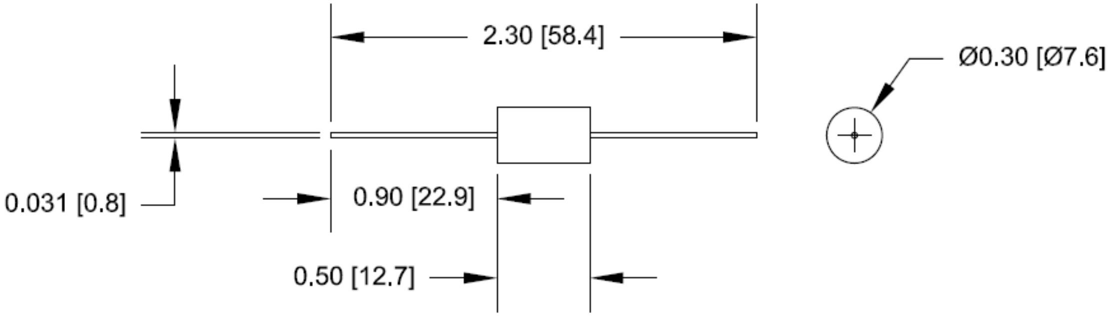


	R_{DSon} [mΩ]	Number of chip	C_S [nF]	f_{OCS} [MHz]	L [nH]	f_Q [MHz]
FF300R12KS4, 62 mm Infineon Si/IGBT	N/A	3	400	1,1	52,1	N/A
CAS300M12BM2, 62 mm Wolfspeed, SiC	4,2	6	180	1,65	51,4	0,082
CAS325M12HM2, Wolfspeed, SiC	3,6	7	66	6,3	9,6	0,374
GE1209003A0, TO247 GE, SiC	25	1	20	9	15,6	1,607

SiC Pin Diode – 10 kV / 2 A





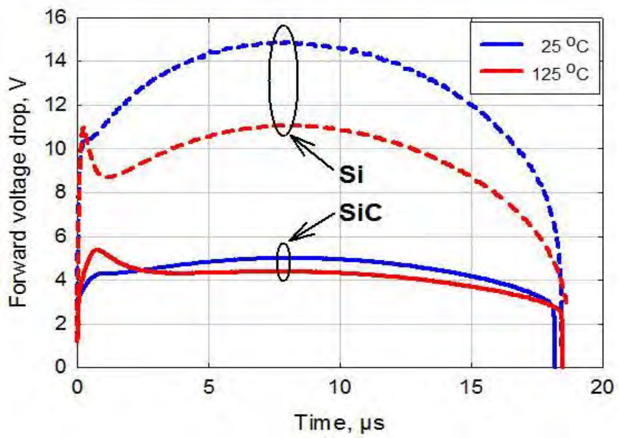


Co-funded by VINNOVA

Manufact. ASCATRON

HV-Diode (10 kV/2 A)

Dynamic measurements, on-state voltage and reverse recovery



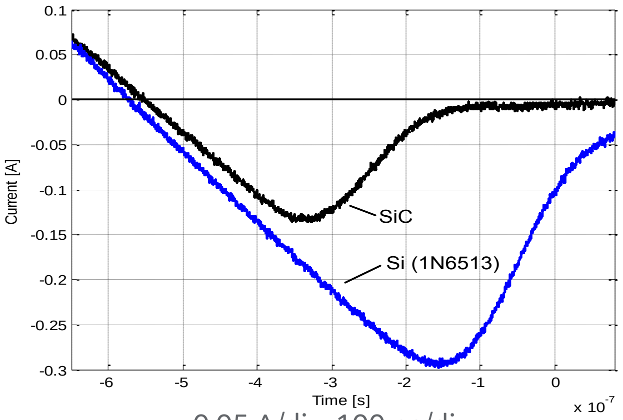
On-state voltage

SiC 10 kV, 2 A
Si 10 * 1 kV, 3 A

î=2 A, f=30 kHz

Conduction losses

Diode	P_{ON} (125 °C) [W]	P_{ON} (25 °C) [W]
Ref Si	12.9	17.5
SiC	5.15 ± 0.09	5.7 ± 0.16



0,05 A/div, 100 ns/div

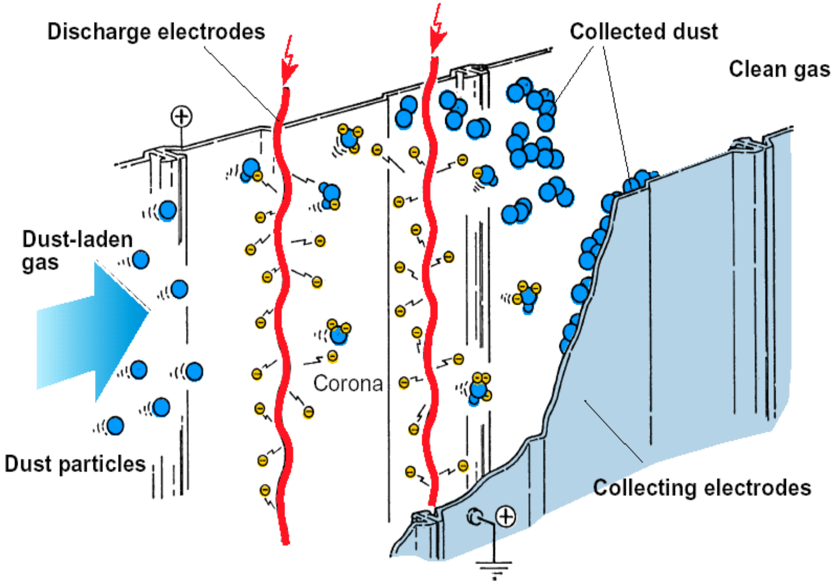
Reverse recovery

T_J 125°C

Conduction losses reduced by 2/3

Loss per device 3 times higher !

Field testing



Test systems in industrial operation

Total operation time, > 5 yrs

Performance and reliability demonstrated

Highly Efficient Power Supplies

Conclusions 2

SiC Power Devices can

- ➢ **improve performance**
- ➢ **reduce operation cost**

Measured loss reductions, 2/3 experimentally verified

System cost benefits over Si is expected

-Higher power density overrides more expensive SiC components

-Low loss at high frequency is key

Reliability

-No critical effect observed-continue to follow carefully

-Expected to improve vs Si

Technology demonstrated in industrial operation, >50000 h

Related publications

“Humidity Testing of SiC Power MOSFETs - An Update”,
D.–P. Sadik, F. Giezendanner, P. Ranstad, and H.–P Nee
IEEE European Conference on Power Electronics and Applications (EPE) 2017

“Short-Circuit Protection Circuits for Silicon Carbide Power Transistors”, *I*
D.–P. Sadik, J. Colmenares, G. Tolstoy, D. Peftitsis, M. Bakowski, J. Rabkowski and H.–P. Nee
IEEE Transactions on Industrial Electronics 2016.

“Investigation of long-term parameter variations of SiC power MOSFETs,”
D.-P. Sadik, J.-K. Lim, P. Ranstad, and H.-P. Nee
Power Electronics and Applications (EPE’15 ECCE-Europe), 2015

“Design and Characterisation of Newly Developed 10kV/2A SiC PiN Diode for Soft Switching Industrial Power Supply”,
M. Bakowski, P. Ranstad, J-K. Lim, W. Kaplan, S. A. Reshanov, A. Schoner, F. Giezendanner, and A. Ranstad.
IEEE Transactions on Electron Devices, 2015.

“An experimental evaluation of SiC switches in soft-switching converters”,
P. Ranstad , H.-P. Nee, J. Linner, and D. Peftitsis.
IEEE Transactions on Power Electronics, 2014.

“On dynamic effects influencing IGBT losses in soft switching converters”,
P. Ranstad and H.-P. Nee
IEEE Transactions on Power Electronics, 2011.