

**REINHOLD ENVIRONMENTAL Ltd.**



**2013 APC Round Table  
& Expo Presentation**

**July 8-9, 2013, in St. Louis, MO / Hosted by Ameren**

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# Energizing ESPs with High Frequency Power Supplies 20 years of operation Experiences and Future solutions

PCUG/Round Table  
Reinhold Environmental

Dr. Per Ranstad

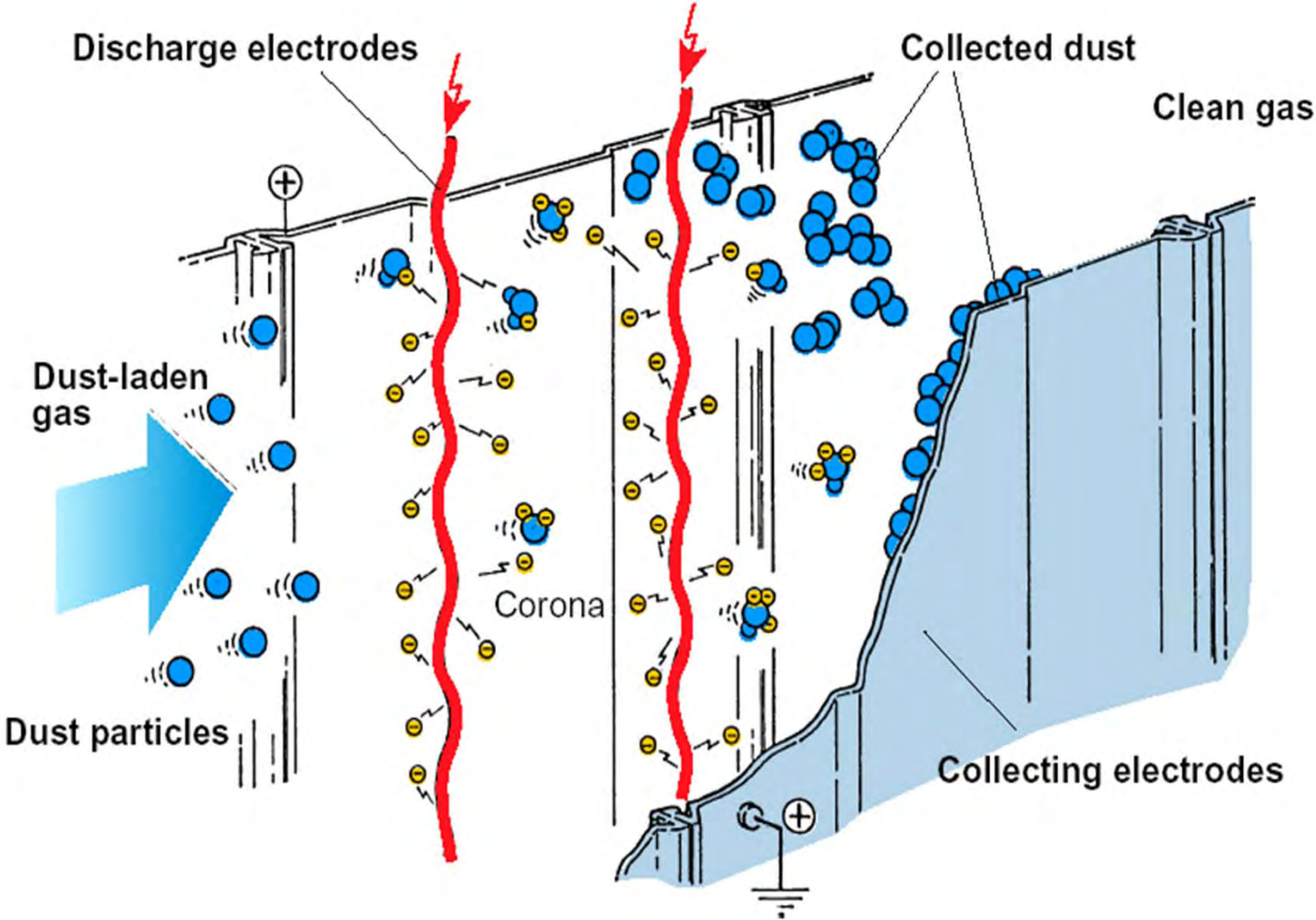
St. Louis, July 9th, 2013

POWER

**ALSTOM**

- ***Introduction***
- *Experiences*
- *Future perspective*
- *Summary*

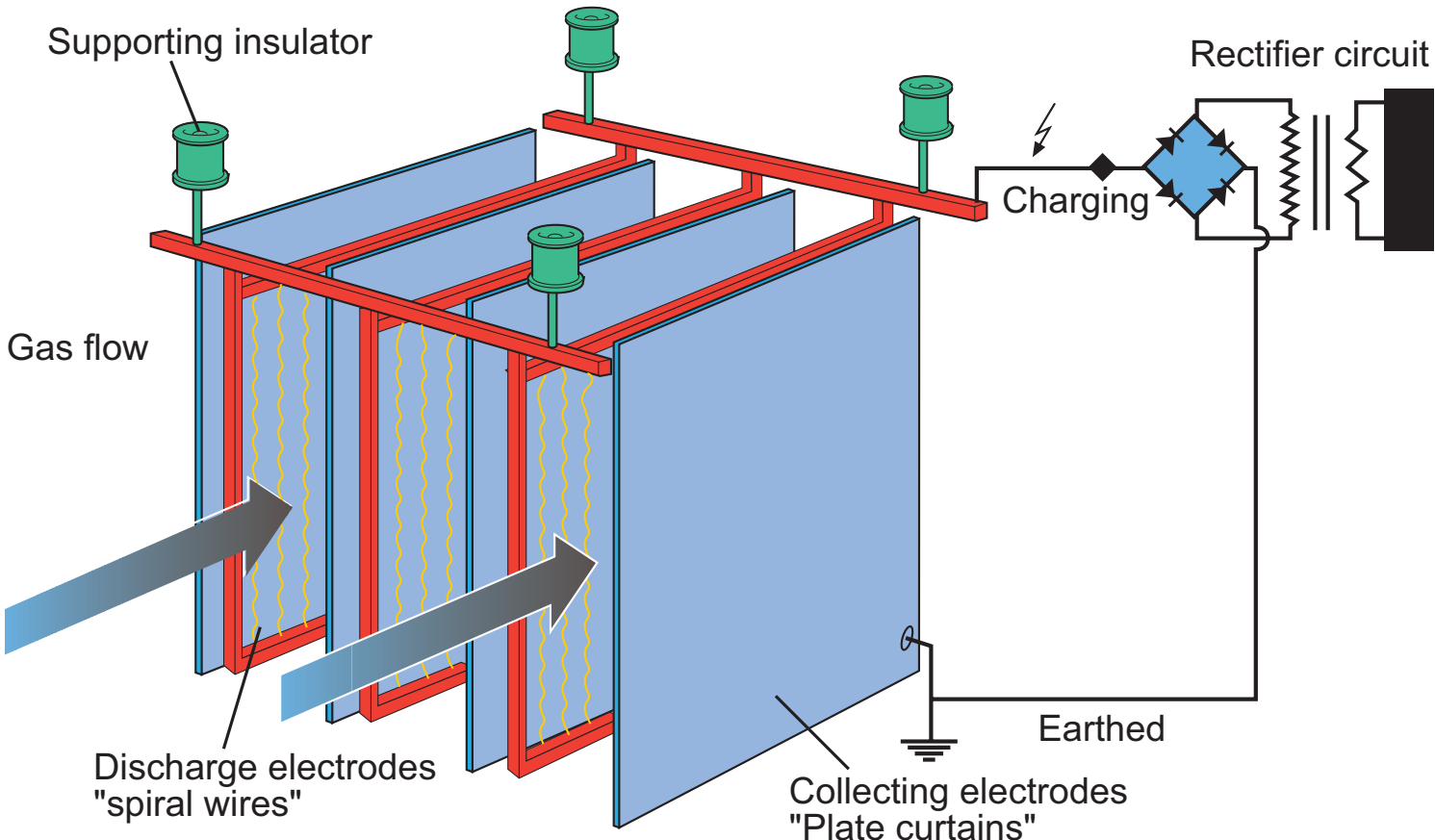
# ESP dust collection



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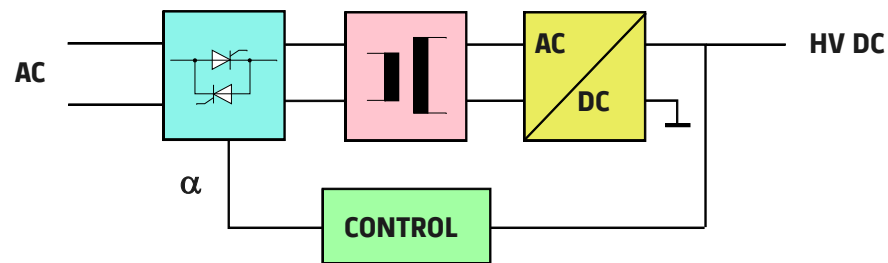
# Principal design of Electrostatic Precipitator



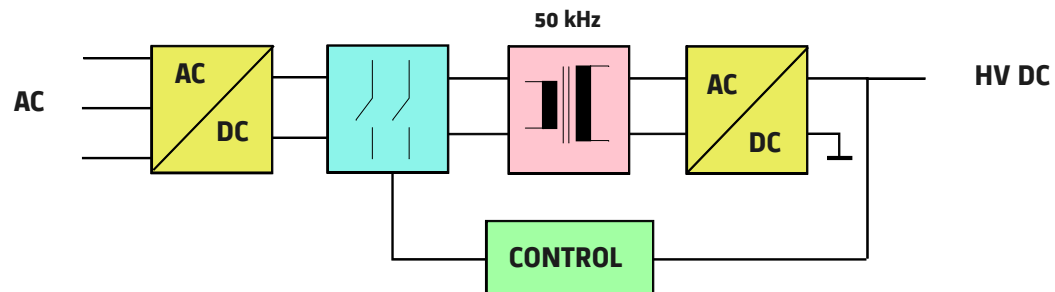
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## Mains frequency power processing



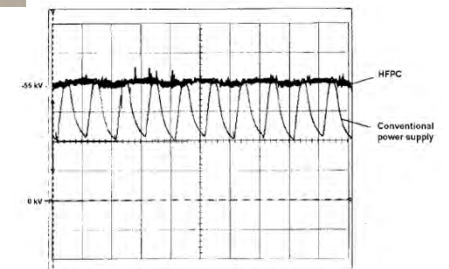
## High frequency power processing



# SIR - Switched Integrated Rectifier, some important mile stones

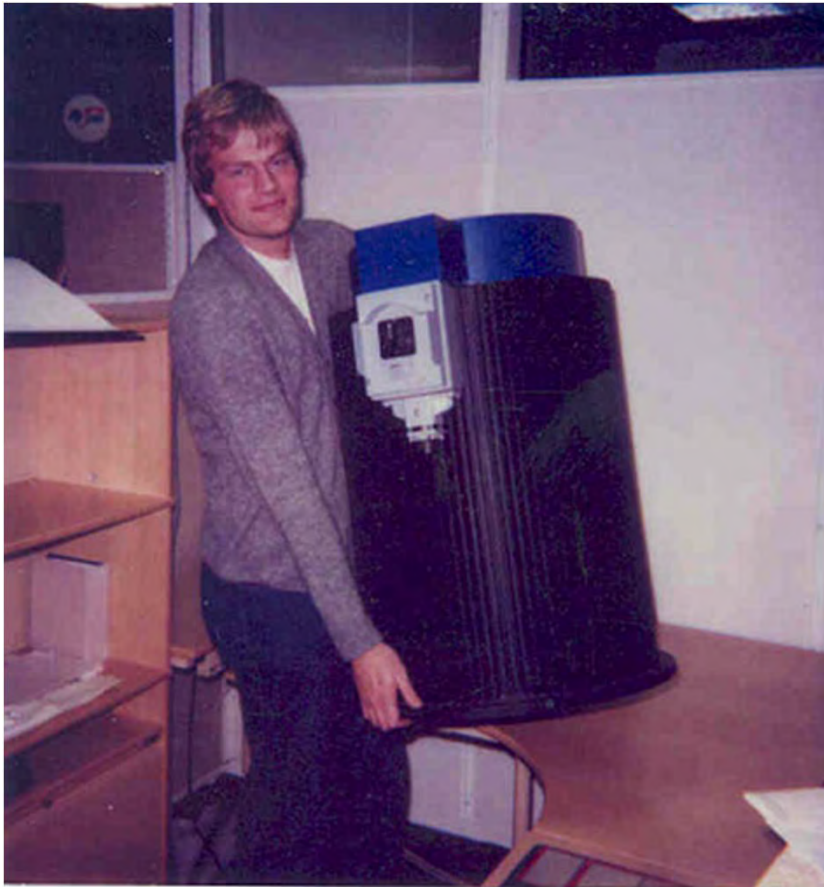


- 1987 First prototype operating on an ESP
- 1993 First commercial installation
  - SIR 80 kV / 250 mA (April 7<sup>th</sup>)
- 1995 Original publ. on HFPS, EPRI/DOE, Toronto
  - Ranstad, Porle “High Freq. Power Conversion: A New technique for ESP energization”
- 1998 60 kW model introduced
- 2006 120kW model introduced
- 2011 Recipient of the ISESP Masuda award



# Prototype 1, 60 kV/200 mA, (-87) some goals **ALSTOM**

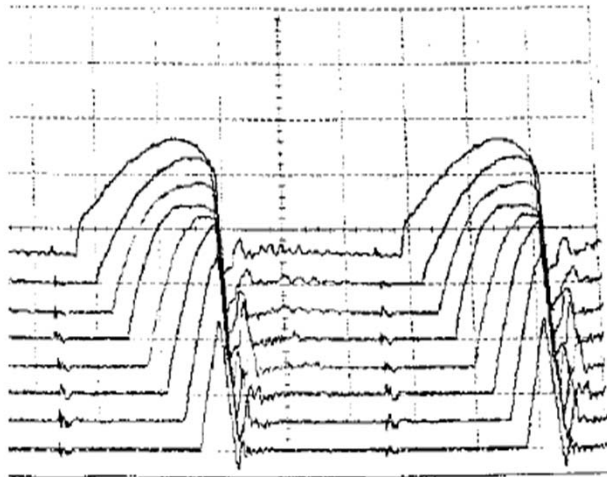
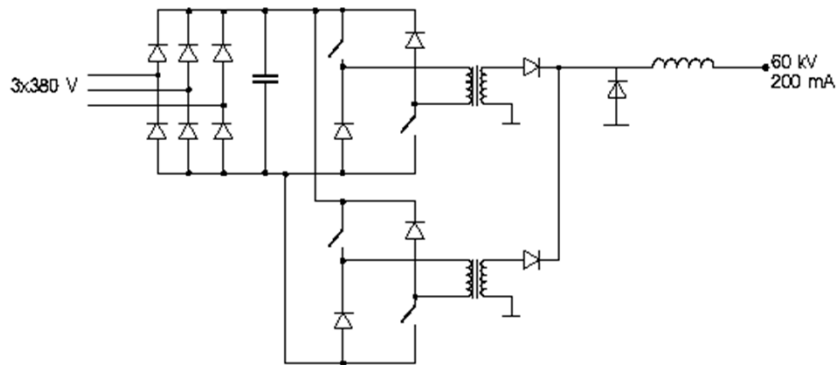
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## Project targets:

- Low weight
- Compact
- Pulsing capabilities
- Minimum losses
- Easy to install
- Market introduction, 1 year

# Prototype 1 (-87), 60 kV/200 mA



## Lesson learned

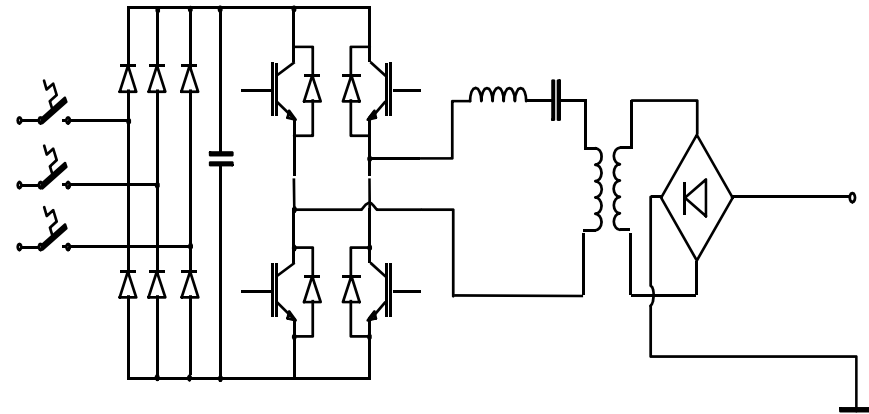
- Efficiency
- Integration of transformer parasitic elements
- Capacitive load
- Current source

# SIR - Prototype 2 (-88)

## 80 kV / 250 mA



- Resonant converter, SLR
- Soft switching
- Integration of transformer parasitic elements
- Capacitive output filter
- Insulated Gate Bipolar Transistor (IGBT)
- Oil impregnated transformer



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# SIR is serving the industry for 20 years



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# SIR is serving the industry for 20 years



## Rättviks Kalk

Lime kiln with three lines

- #1 ESP 1&2 (single syst.) , -93
- #2 ESP 3 (two syst.) , -03
- #3 ESP 4 (two syst.) , -93

Upgrade projects included:

- Internals
- Power supplies
  - SIR 80 kV/250 mA



# SIR is serving the industry for 20 years



## Rättviks Kalk

In 1993 line #1 and line #3 were upgraded, and Oct/Nov and May/April respectively. Line #3 was put in commercial operation April 7<sup>th</sup>.

The SIRs on line #3 has reached 20 years of operation, in total line #1 and #3 has accumulated 80 years of operation with 100% availability.



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# SIR , ESP power supply



Model	Output	First inst.
SIR	80kV/250mA	-93
SIRA	70kV/400mA	-97
SIRE	70kV/800mA	-98
SIR4	70kV/1700mA	-06
SIR4	100kV/1200mA	-08
SIR4 102	85kV/1200mA	-12



# ESP High-Frequency Power Supplies



ALSTOM (SIR) -93



NWL (PowerPlus) -99



Stock (ModuPower) -08

# Examples of HFPS 国内高频电源



- *Introduction*
- ***Experiences***
- *Future perspective*
- *Summary*

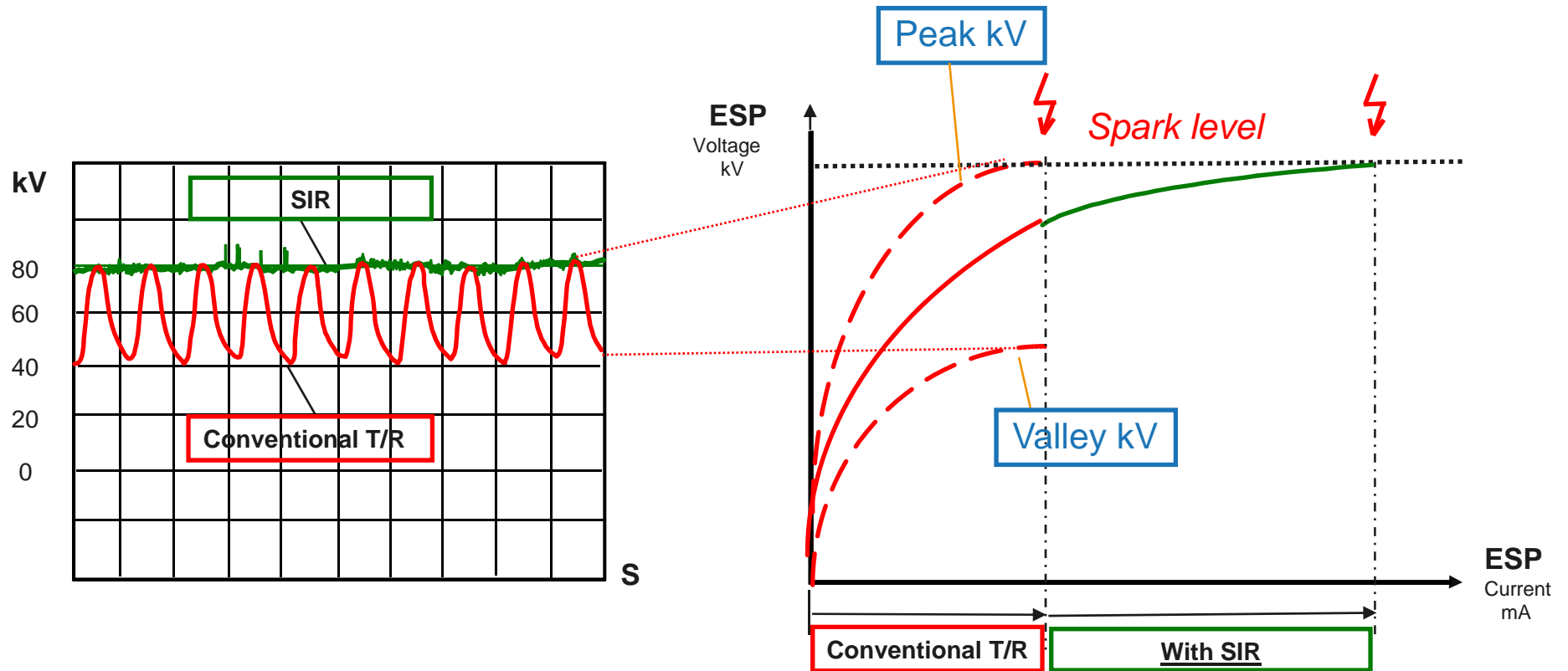
## Improved ESP performance:

- Improved charging of particles
  - Higher current
- Improved particle migration
  - Increased E-field
- Reduced reentrainment
  - Higher current, low ripple
- More precise control
  - Spark over recovery
  - Shorter blocking
  - Pulsing

## Reliability issues:

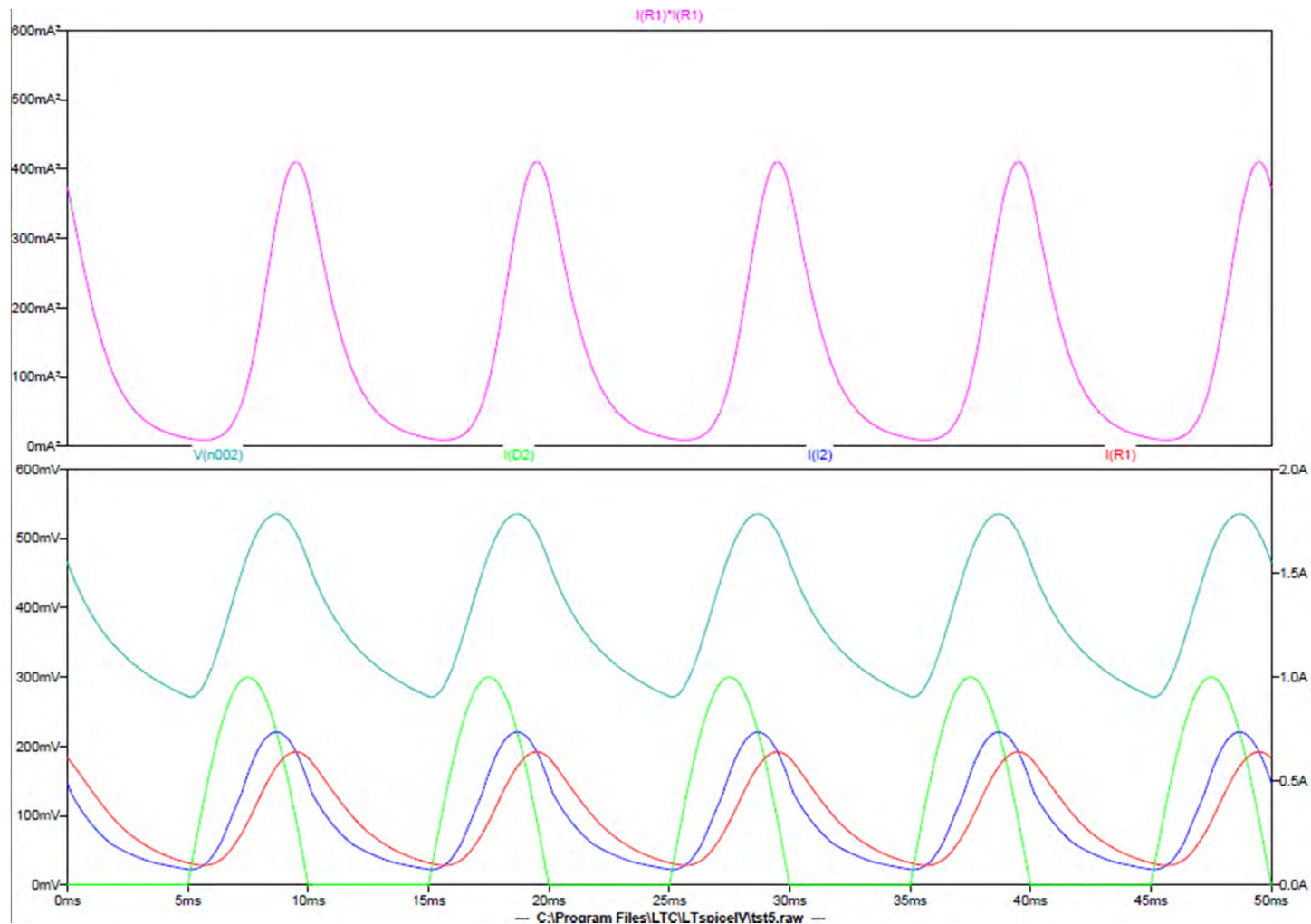
- Installations
- Components
- Production proc.

# HFPS vs. Conventional T/R Electrical Performance – Output Voltage



# Conventional T/R, 1:1 operation

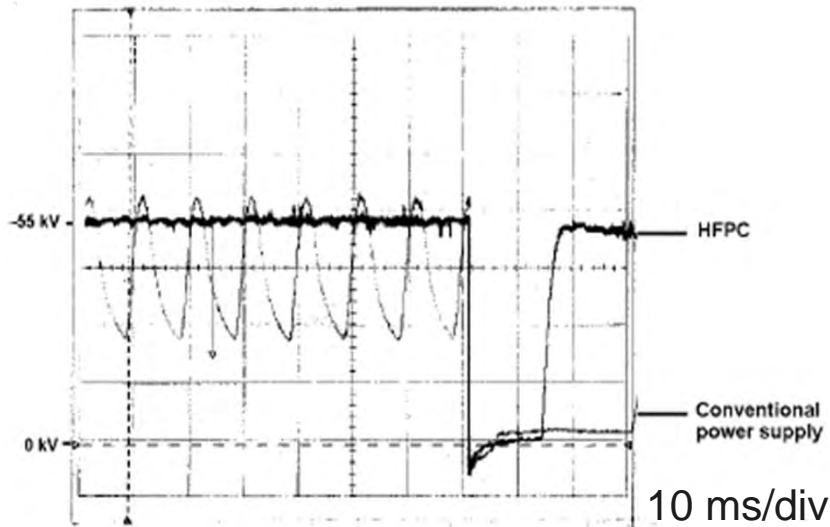
$T=1\text{ ms}$  ( $10^{10}\ \Omega\text{cm}$ )



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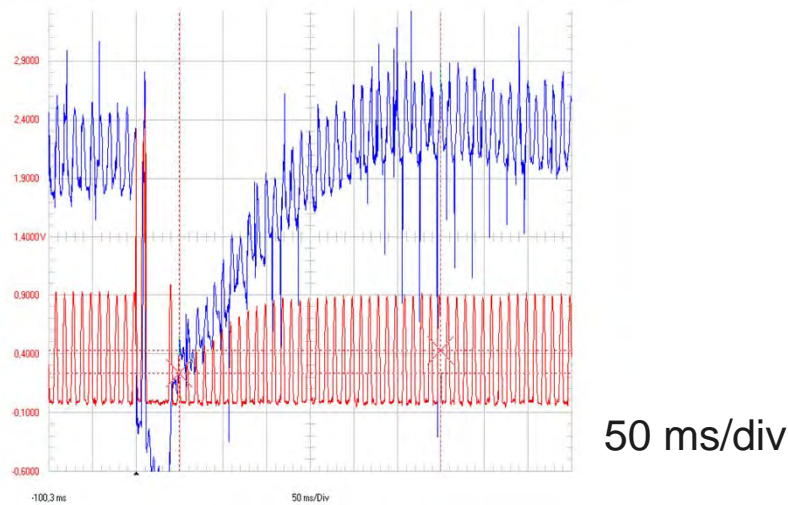
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# Spark recovery

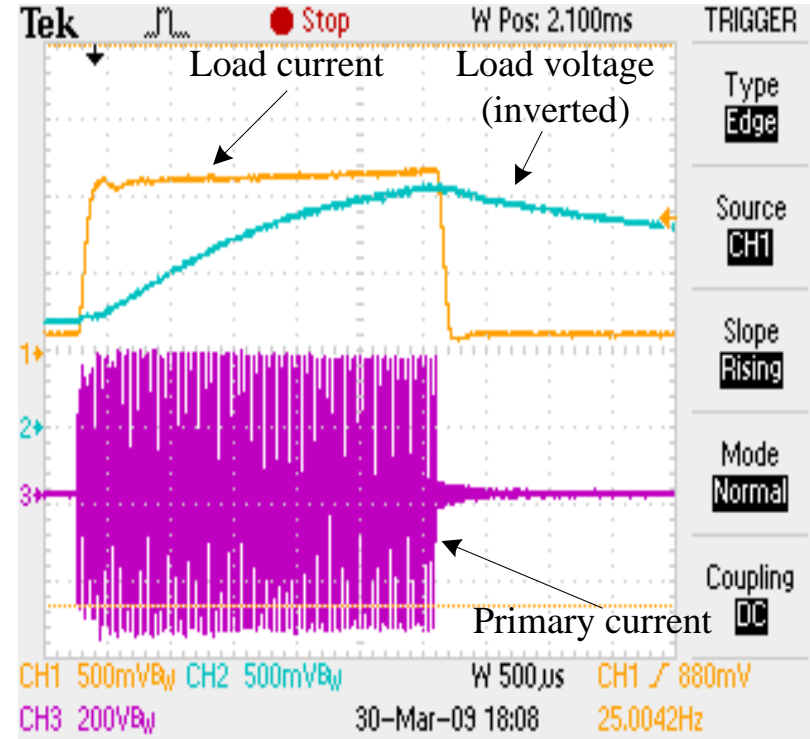
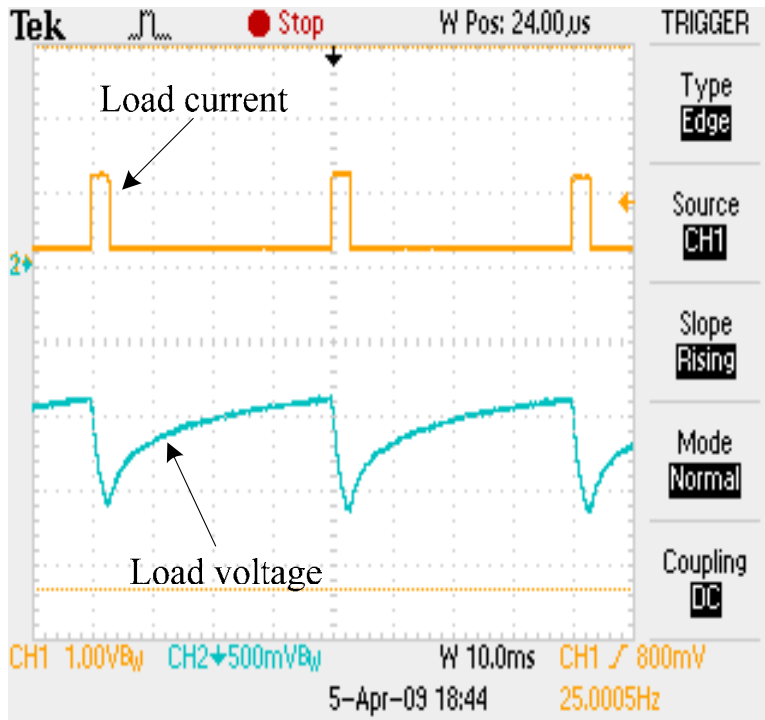


HFPS may have a shorter blocking time, no 50/60 Hz dependency

Superior bandwidth of the control loop (faster) enables improved spark recovery.



# Pulse mode, measured waveforms



- *Introduction*
- *Experiences*
- ***Future perspective***
- *Summary*

## Improved performance due to:

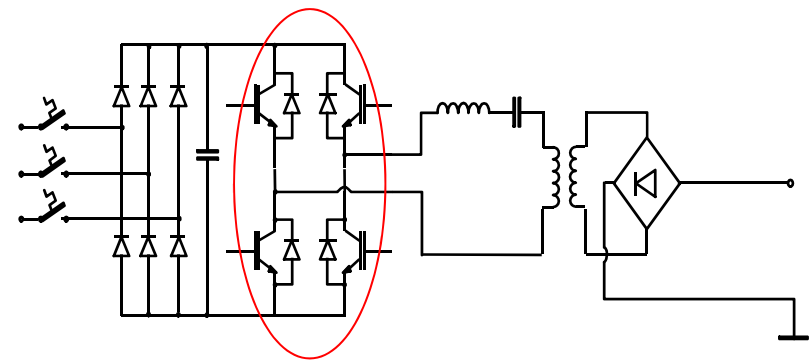
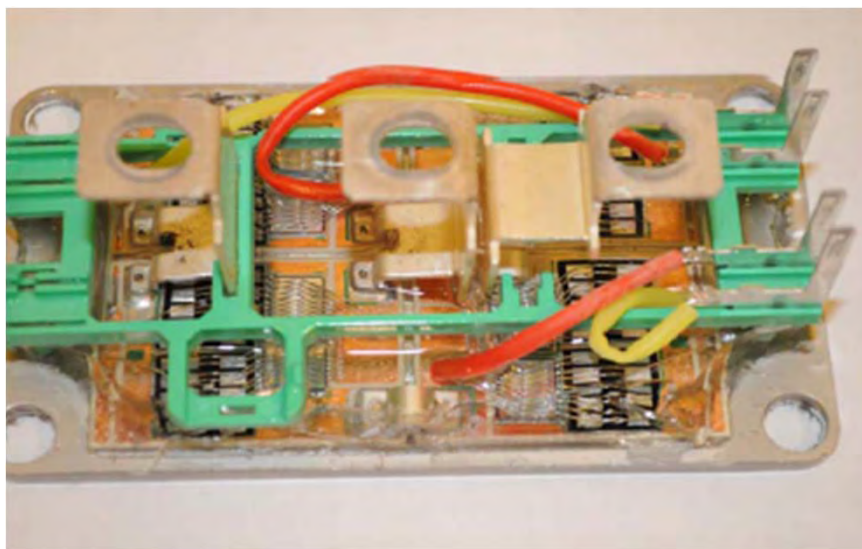
- New materials
  - Higher efficiency
  - Reduced cost
  - Reliability
  
- Improved control
  - Sensor for the ESP
  - Modelling
  - Reliability

# Insulated Gate Bipolar Transistor IGBT (Silicon)



400 A / 1200V

- 4 chips per transistor function
- Total Si area:  
512 mm<sup>2</sup>
- Peak current density:  
30,5 A/cm<sup>2</sup>
- $U_{GE} : 16 \text{ V}$



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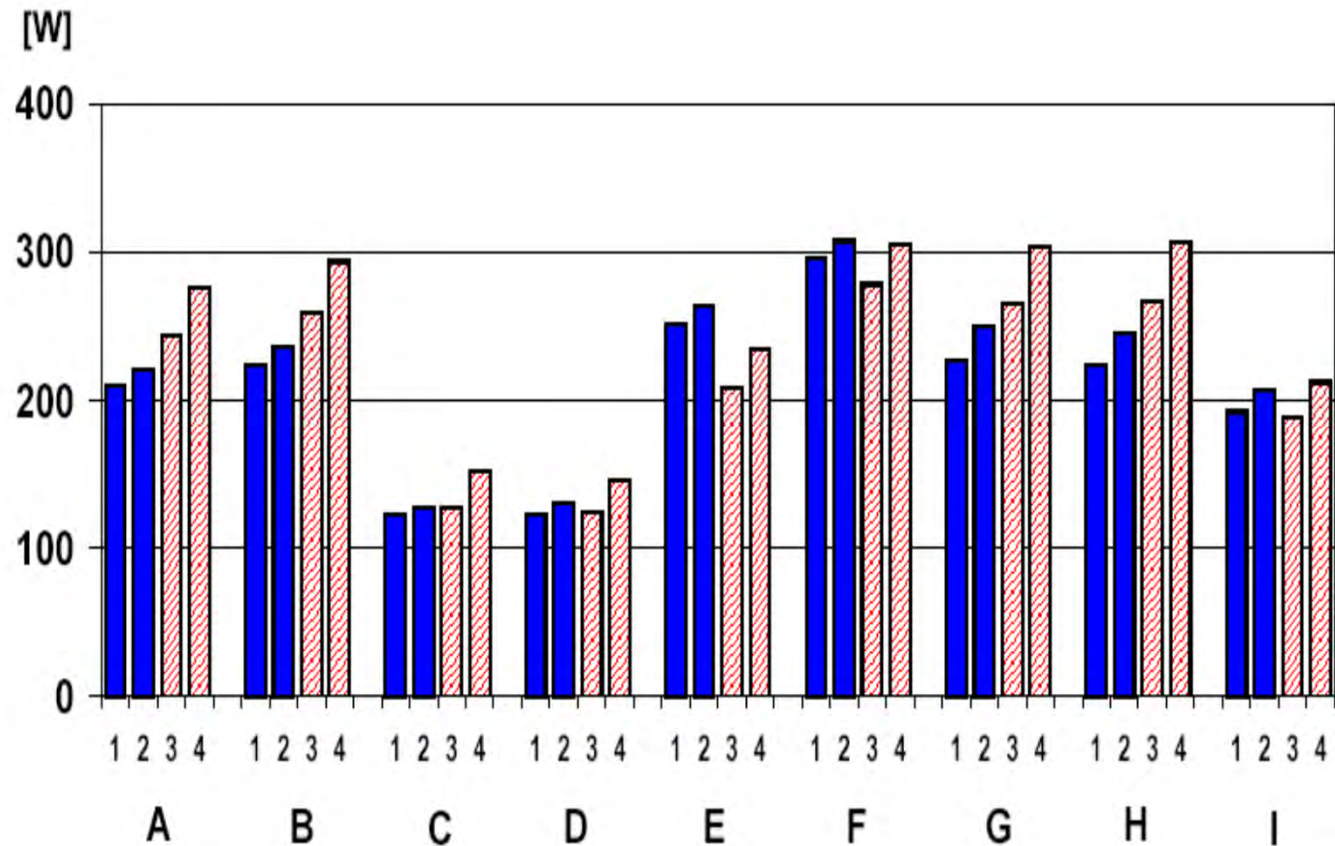
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# IGBT conduction losses

## Experimental results



- 1: 7,5 kHz, 25 °C
- 2: 30 kHz, 25 °C
- 3: 7,5 kHz, 125 °C
- 4: 30 kHz, 125 °C



The conduction losses are dependant of the frequency.

# Wide Band Gap materials for Power Semiconductors



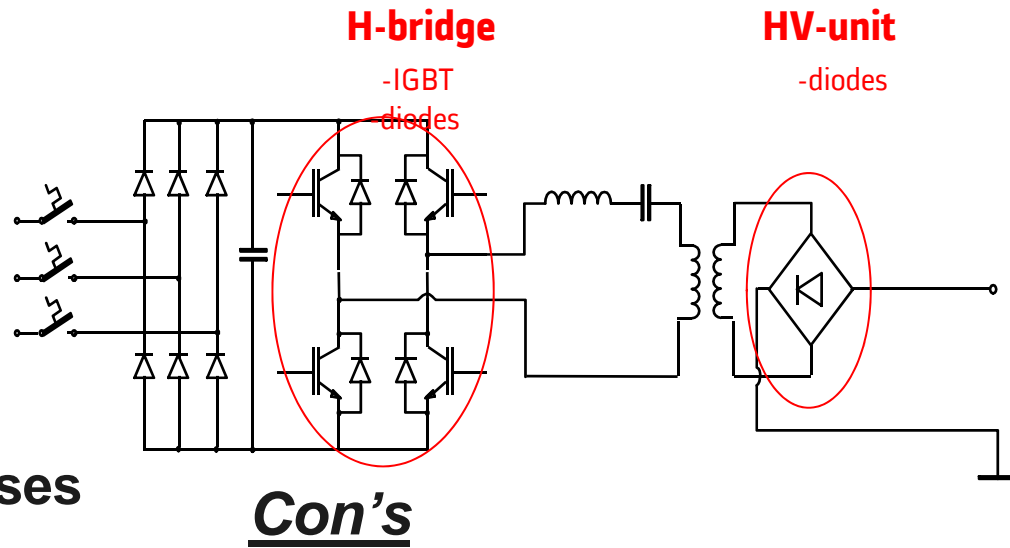
Properties	Si	GaAs	6H-SiC	4H-SiC	GaN	Diamond
Bandgap energy, $E_g$ , (eV)	1.12	1.43	2.9	3.25	3.4	5.5
Critical field strength, $E_B$ , (MV/cm)	0.25	0.4	2.5	2.5	2.0	10
Electron mobility, $\mu_n$ , (cm <sup>2</sup> /Vs)	1500	6500	400	800	900	2000
Thermal conductivity, $\lambda$ , (W/cm K)	1.5	0.5	4.9	4.9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

# New Power Semiconductors

## Potential impact from WBG material

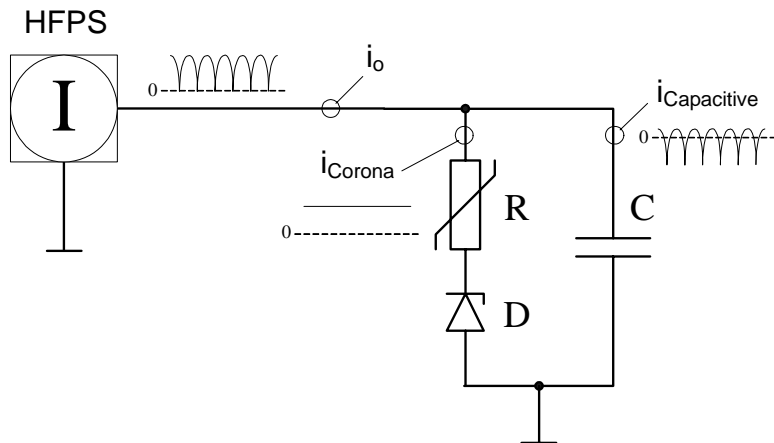
### Pro's

- **Higher efficiency**
  - Power density
  - Operational cost
- **Reduced switching losses**
  - Higher frequency
- **Higher input voltage**
  - $U_{BV} > 1700 \text{ V}$
- **Higher temperature operation**
  - $T_j > 250 \text{ }^\circ\text{C}$
  - Reliability



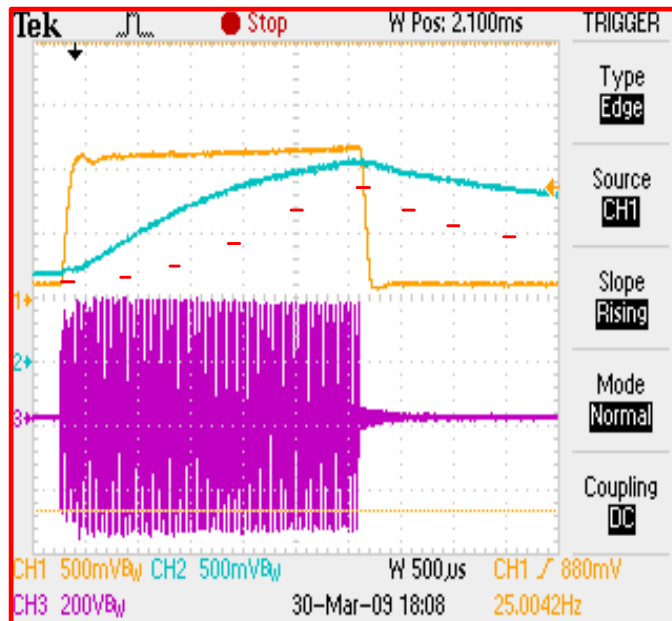
- **Component availability**
  - Low power/low voltage
  - Packaging is an issue
- **Cost aspects**
  - Very high cost on existing components, low power

# Pulse mode



$$i_{Corona} = k \cdot (u - U_{Onset})^2$$

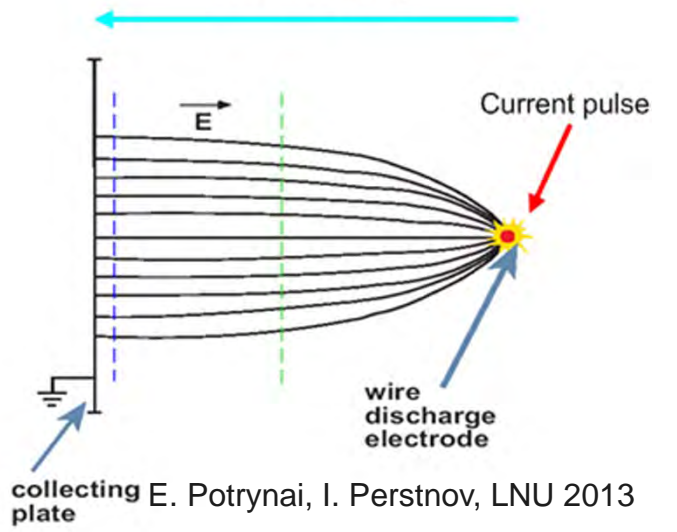
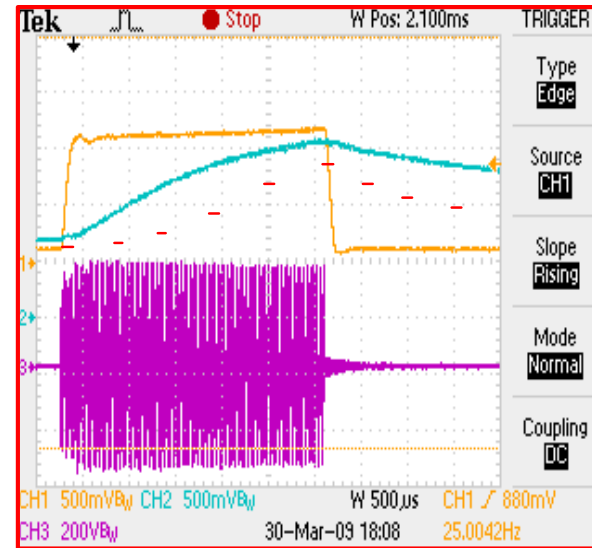
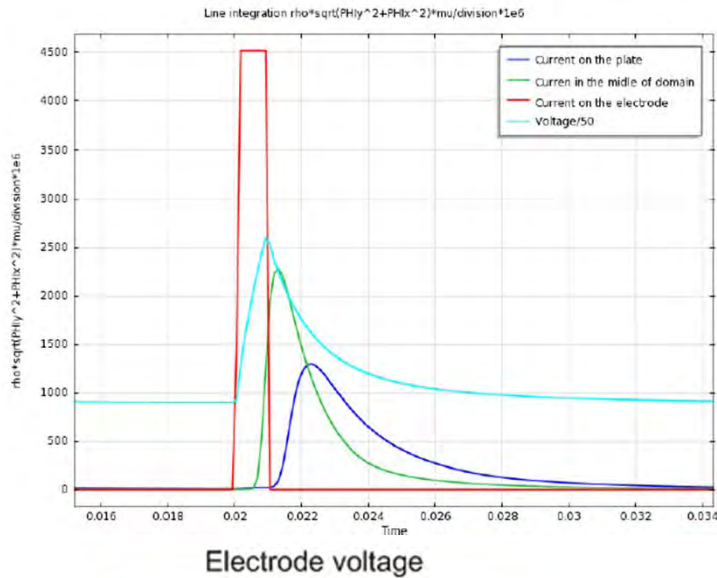
$$i_{Capacitive} = C \cdot \frac{du}{dt}$$



- The charging of the ESP capacitance has a significant influence on the corona-current pulse
- The charge of pulse is conserved

# Modelling of the corona-current pulse (FEM)

## Future control strategies



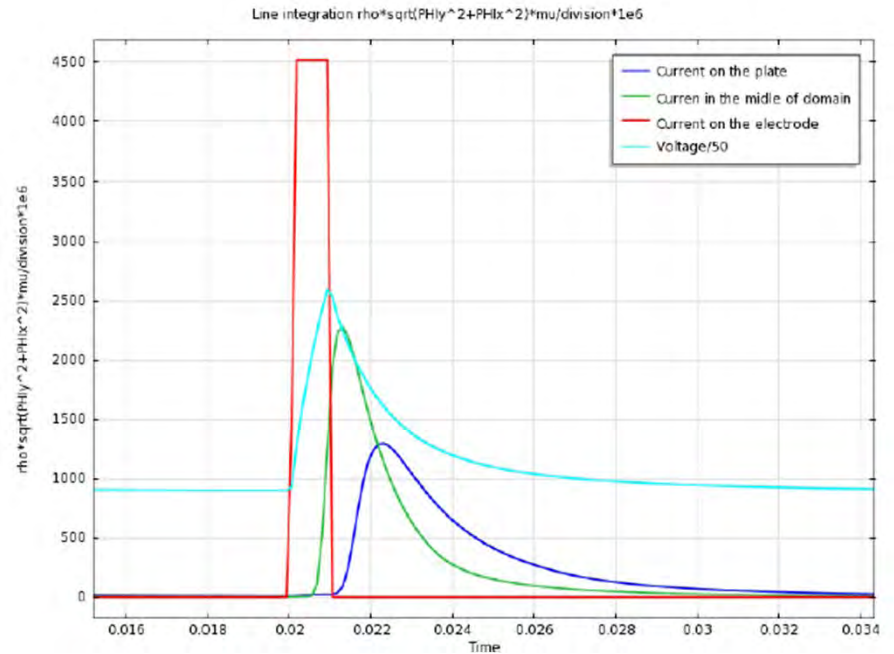
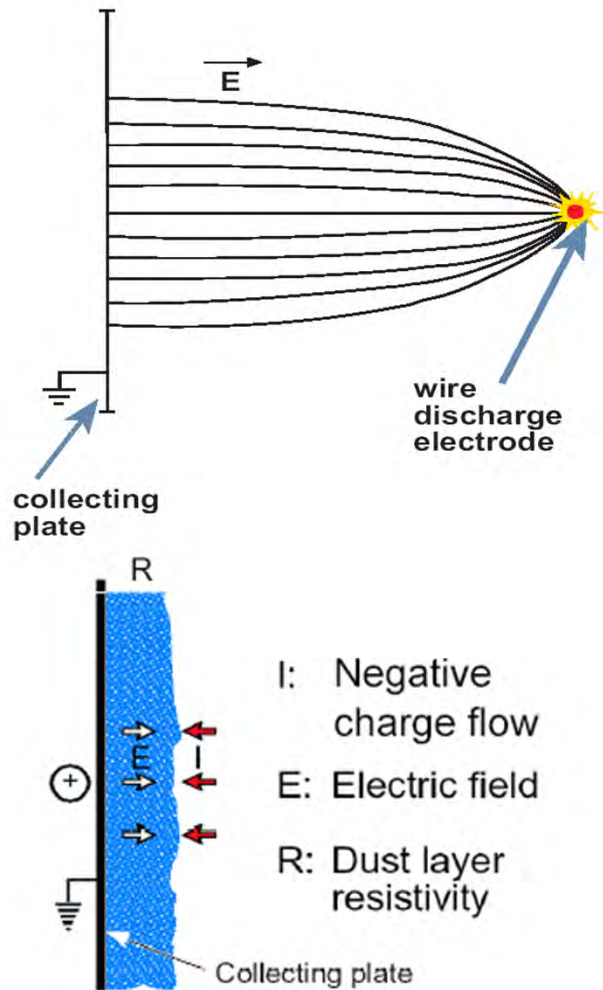
The shape of the corona-current pulse may have a significant impact on ESP performance.

E. Potrynai, I. Perstnov, LNU 2013

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# Gas region and dust-layer



Electrostatic force:

$$F = Q \cdot E$$

- *Introduction*
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- ***Summary***

- 20 years of operational experiences
- HFPS is a proven technology for ESP performance improvements
- Further improvements expected due to new materials and tools

# SIR is serving the industry since 20 years



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