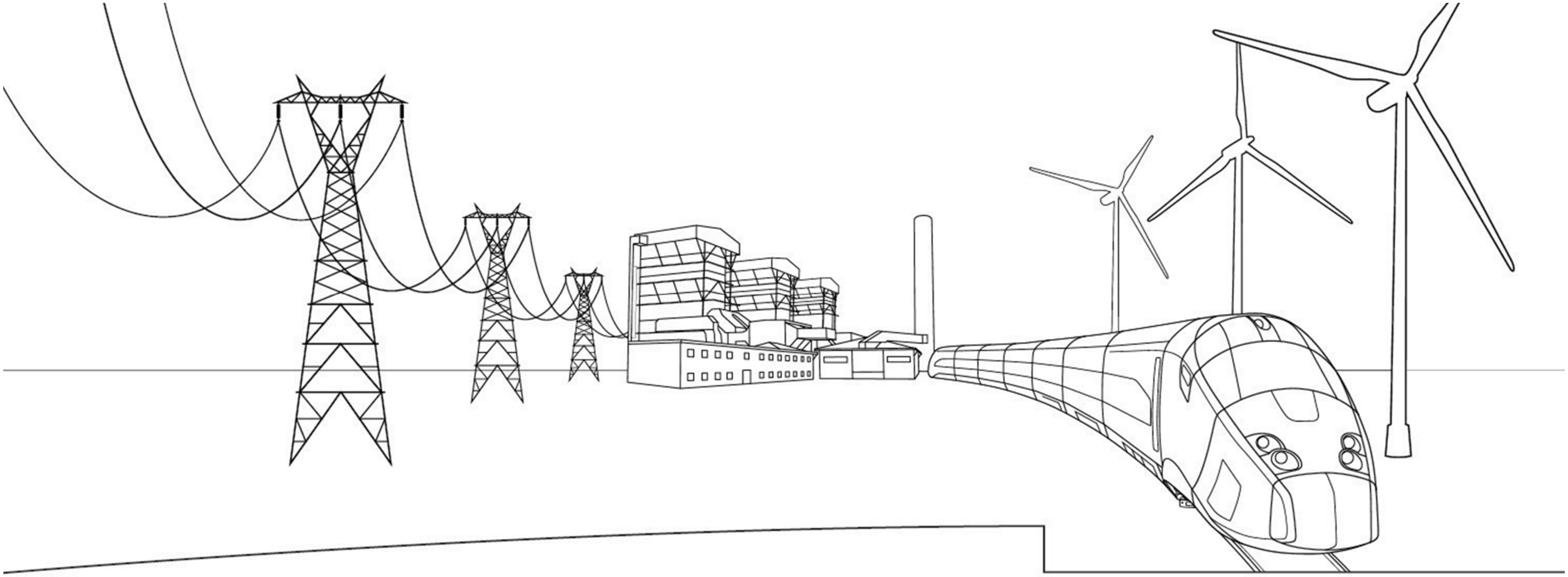
REINHOLD ENVIRONMENTAL Ltd.

2014 APC Round Table
& Expo Presentation

July 14-15, 2014, in Louisville, KY / Hosted by LG&E/KU



Recent Advancements using High Frequency Power Supplies

Reinhold Environmental, Round Table 2014

Per Ranstad, Anders Karlsson

Louisville, July 14th 2014

ALSTOM
Shaping the future

Topics

Introduction

Corona quenching, Fine Dust

Case study

High resistivity, Control of injection

Summary

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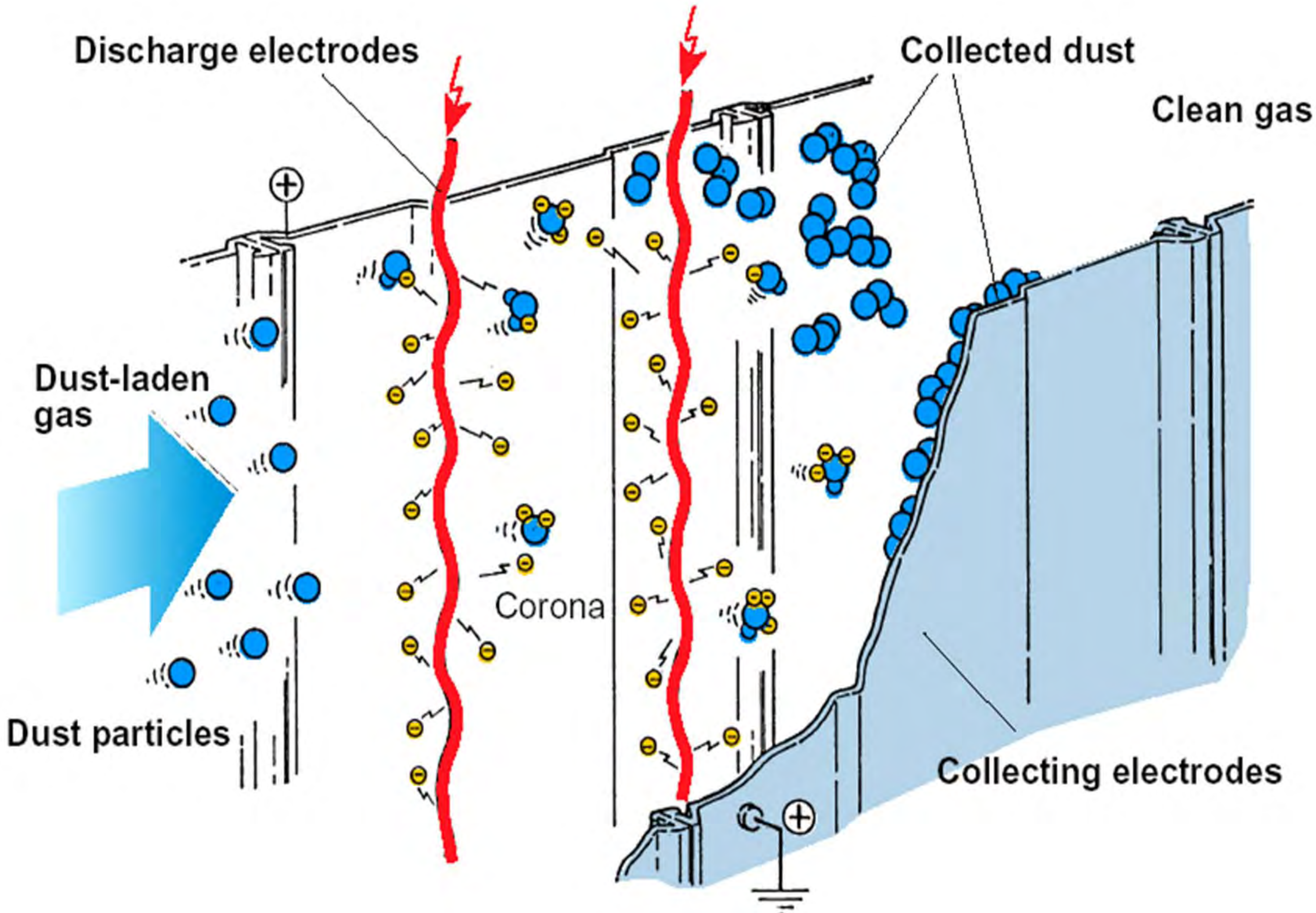
ESP dust collection



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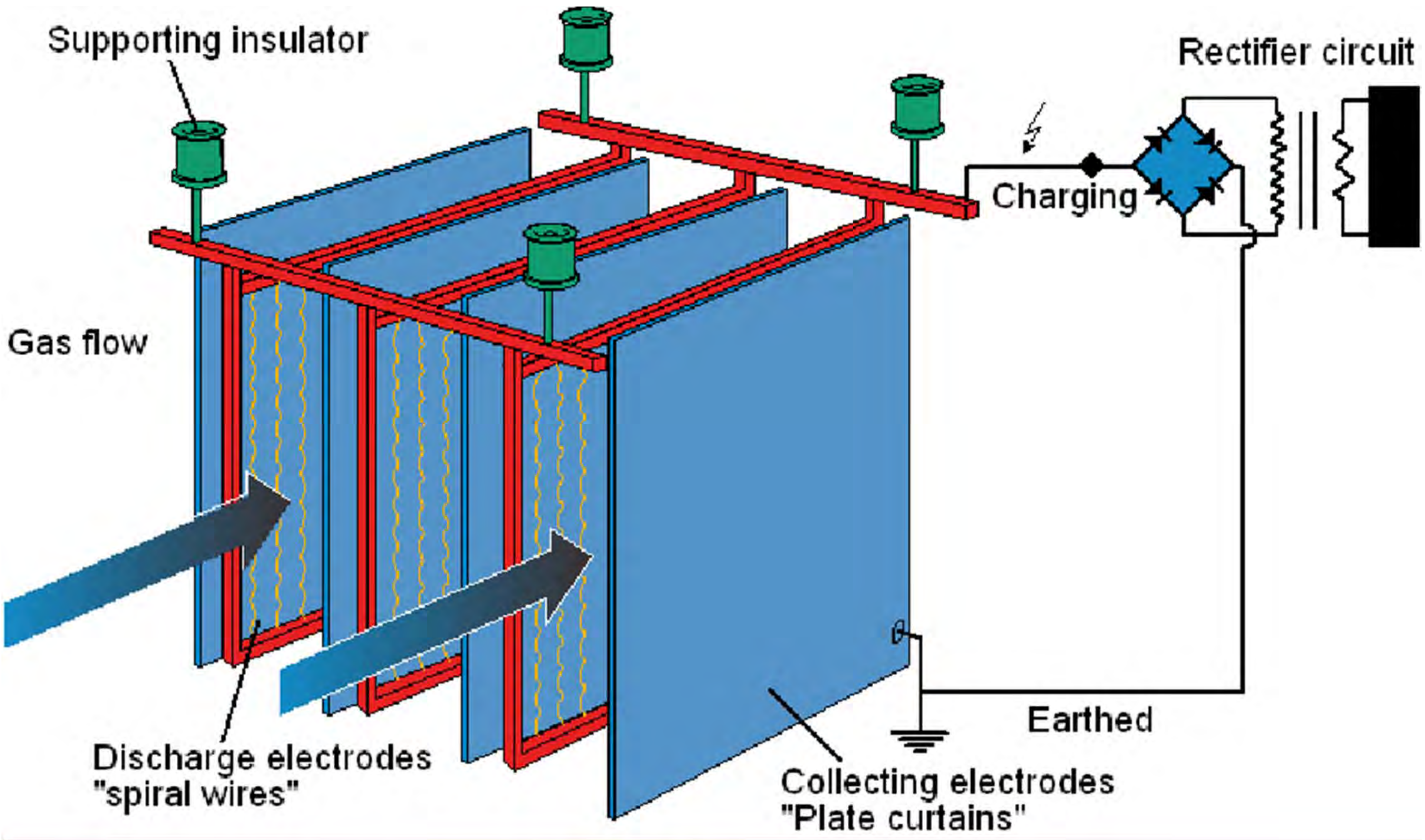
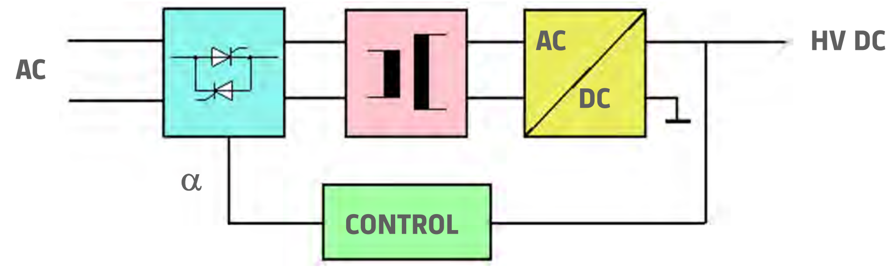
Principal design of Electrostatic Precipitator

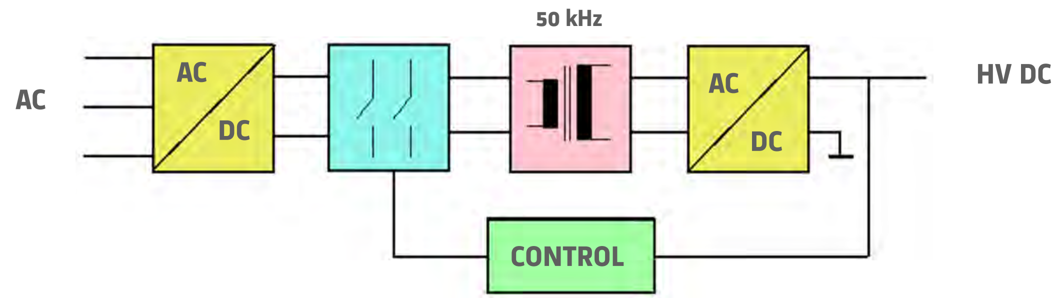


Power processing

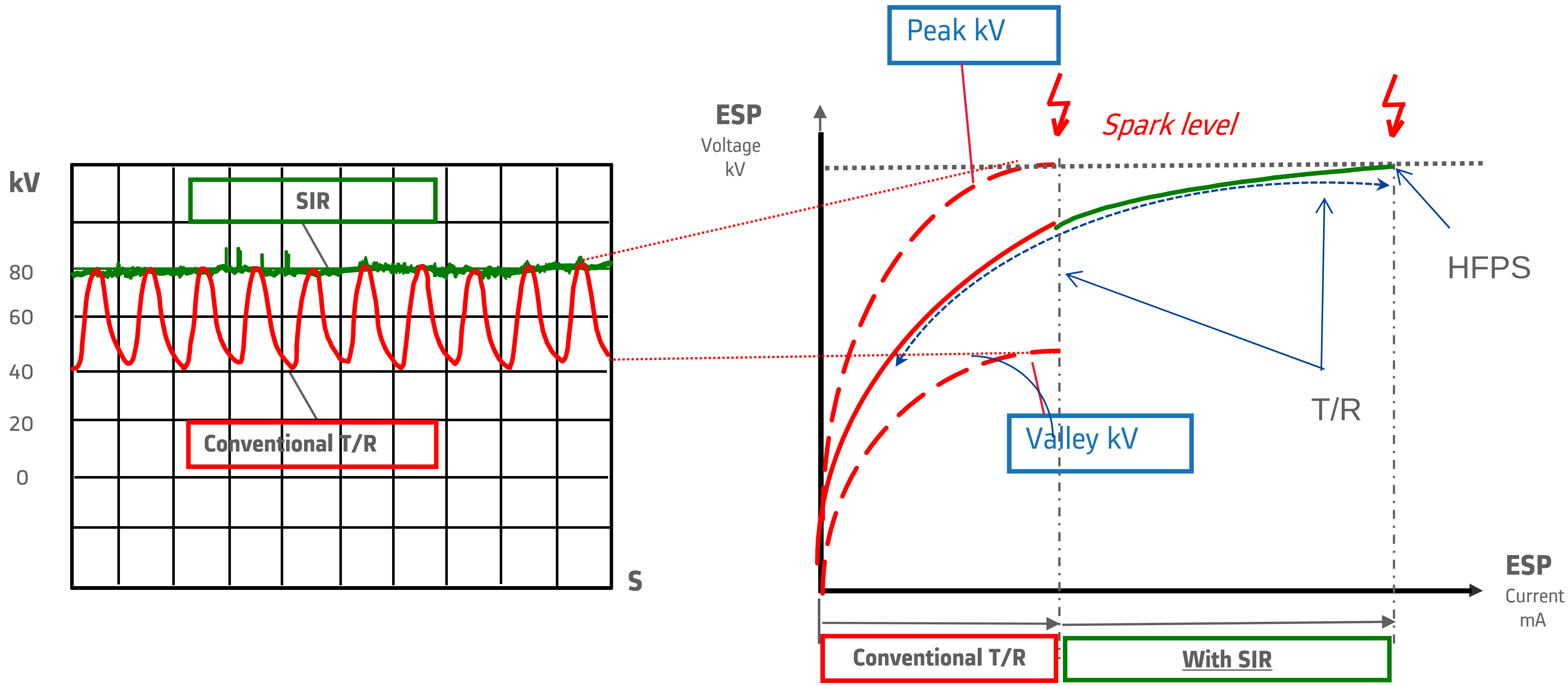
Mains frequency power processing



High frequency power processing



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



Electrical effects

Corona quenching
- Particle size distribution, 'Fine dust'
- Reduce E-field at the emitting electrode
- Less Corona current

Back Corona
- High resistivity dust
- High E-field in the dust layer
- Injects positive charges into the gas

Re-entrainment
- Low resistivity dust
- Low E-field in the dust layer
- Reduced holding forces in the dust layer

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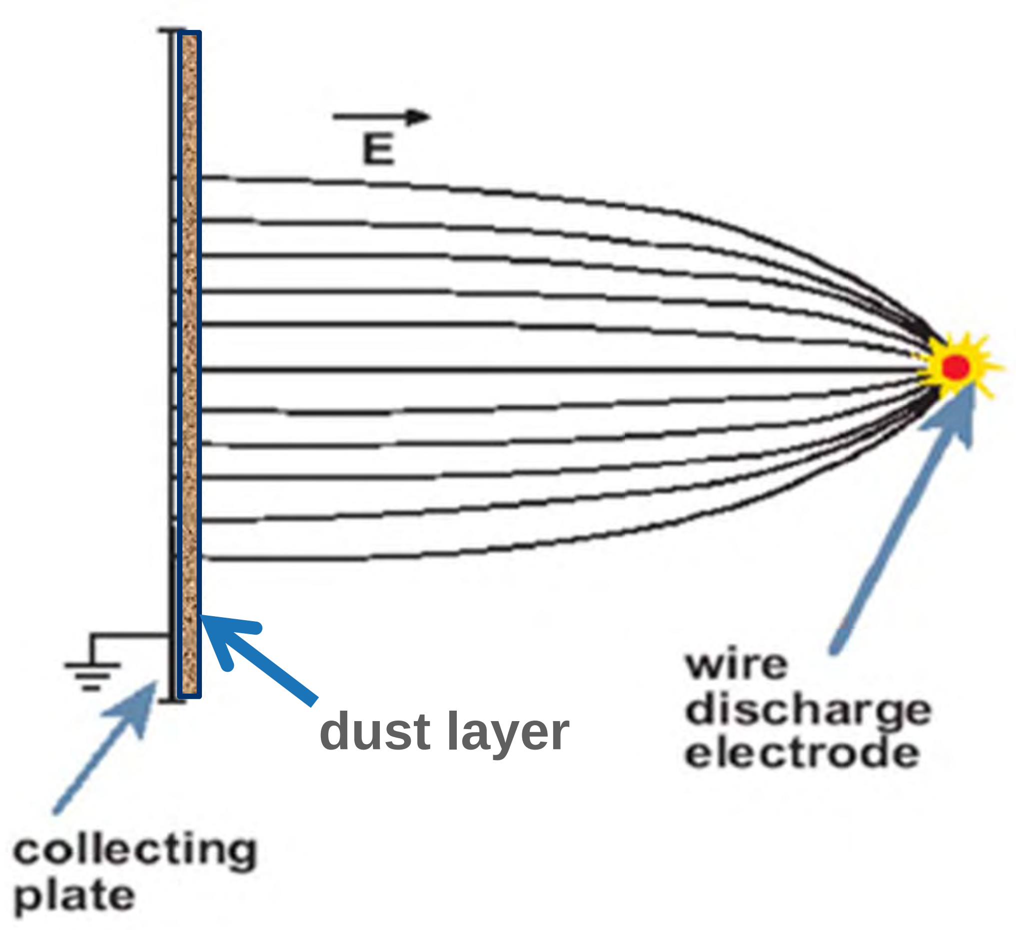
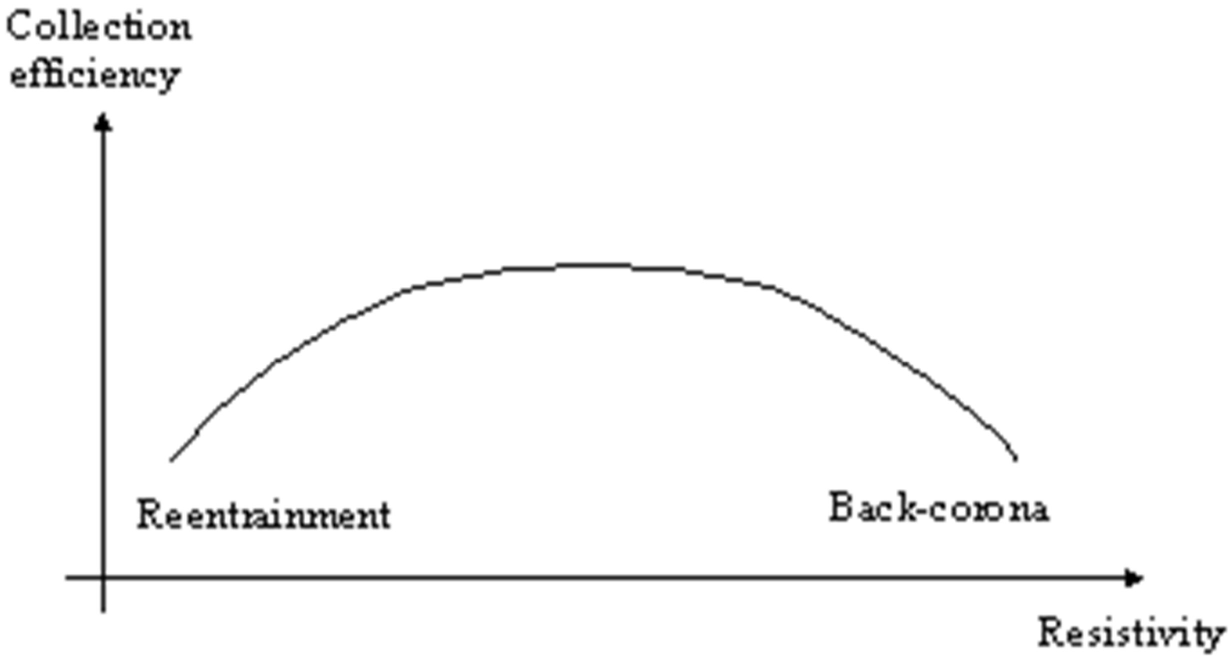
Dust layer and gas region

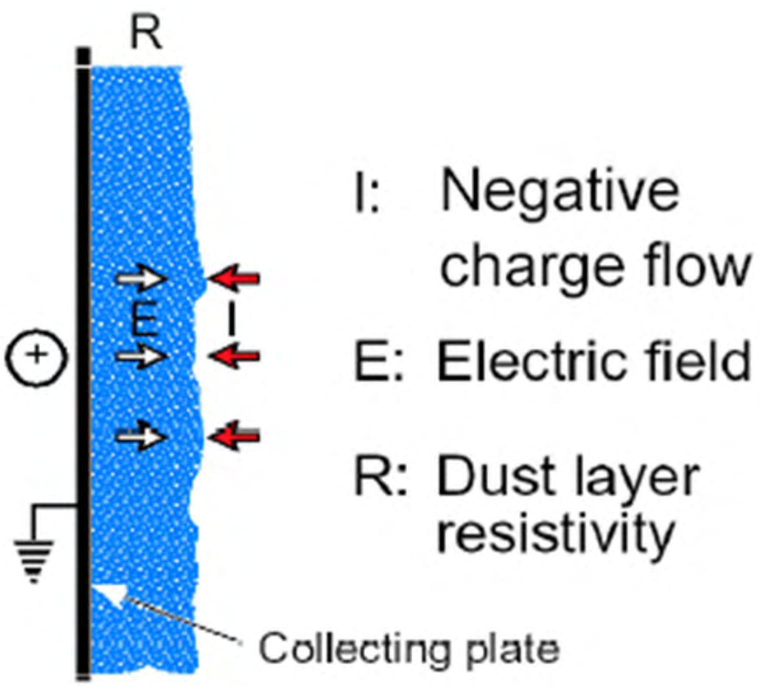


Reinhold Environmental, Rou

Dust emission vs. resistivity



Dust layer, resistivity



Classification 1

Conductive	10^{4}-10^{8} Ωcm
Normal	10^{8}-10^{10} Ωcm
Moderate	10^{10}-10^{11} Ωcm
High	10^{11}-10^{13} Ωcm

[Parker et.al, Applied Electrostatic precipitation, 1997]

Classification 2

Low	10^{7}-10^{9} Ωcm
Best perf.	10^{9}-10^{11} Ωcm
High	10^{11}-10^{13} Ωcm

[Porle, Francis, Bradburn, ESPs for ind. Applications, 2005]

Classification 3

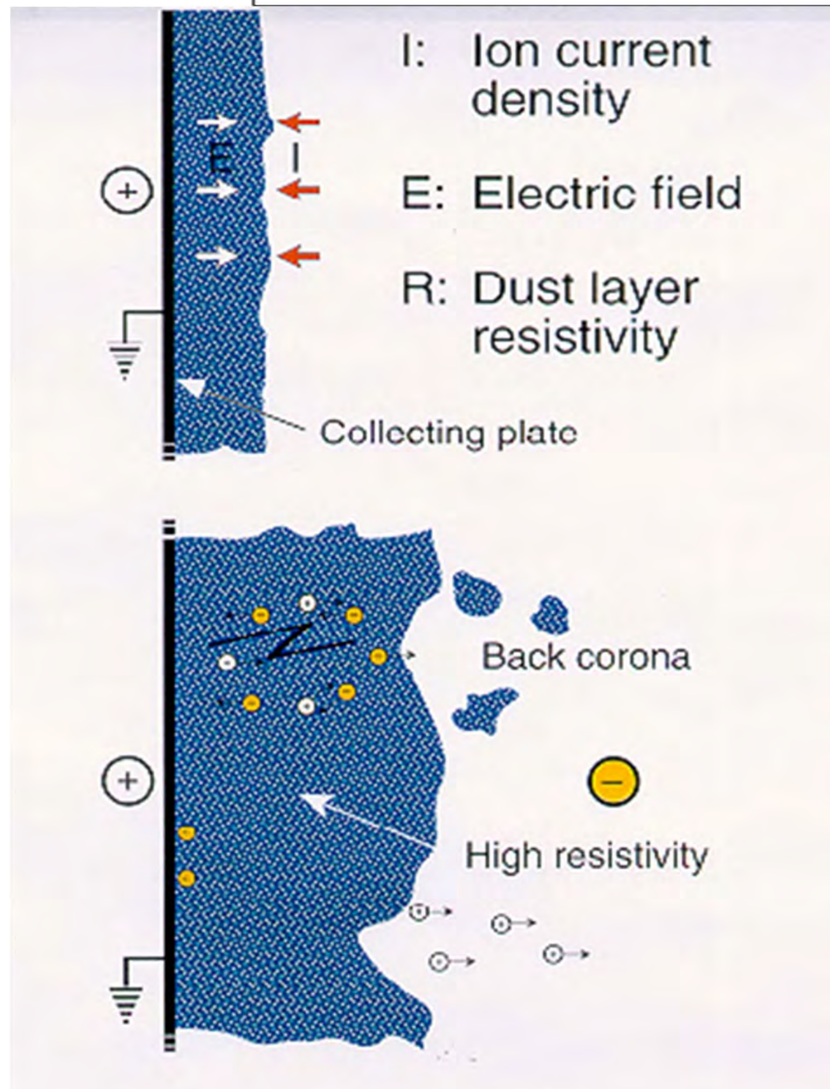
High	$>10^{10}$ Ωcm

[White, Industrial Electrostatic Precipitation, 1963]

Back-Corona and Re-entrainment

$$E = j\,\rho$$

$$F = EQ$$



E *Field strength,* [V/m]
j *Current density,* [A/m²]
ρ *Dust layer resistivity,* [Ωm]
Q Charge, [As]

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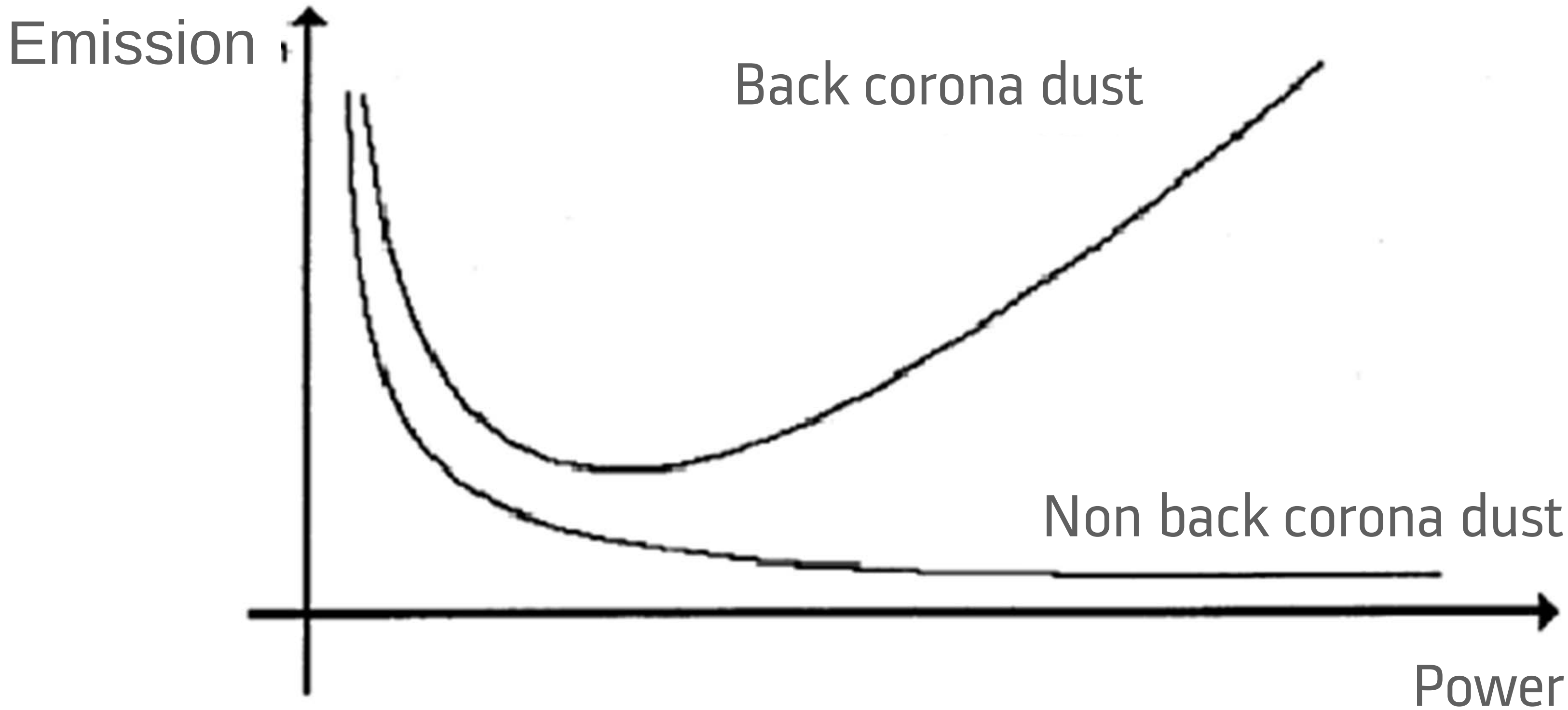
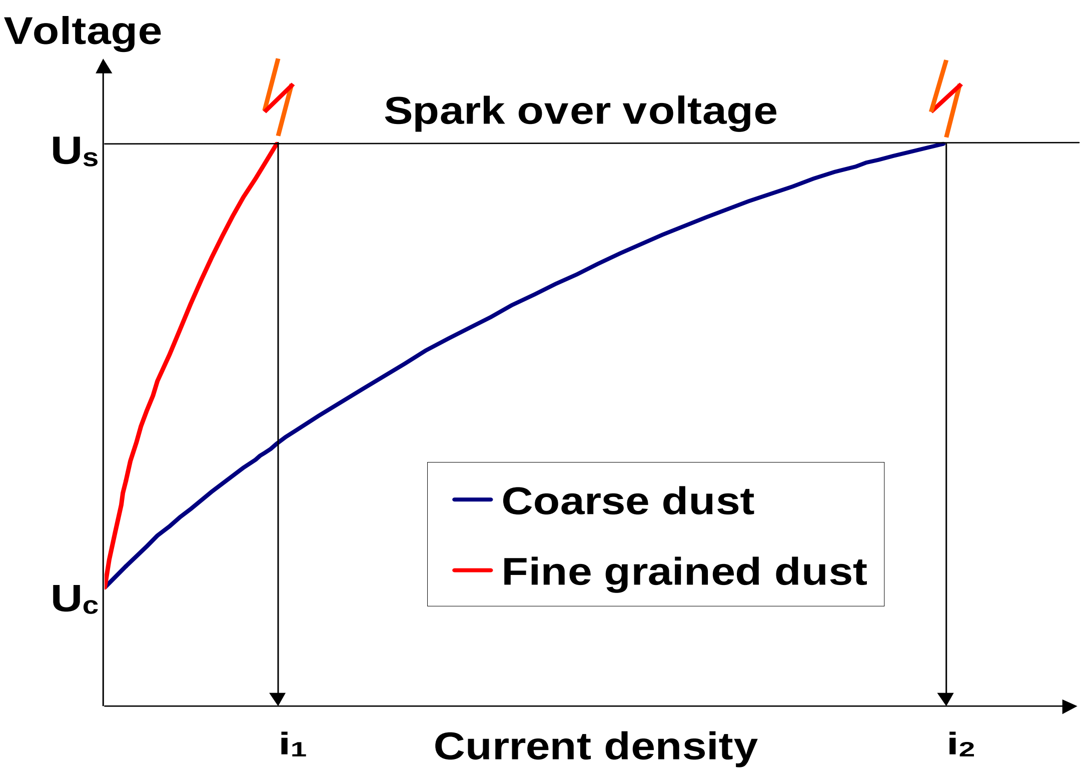
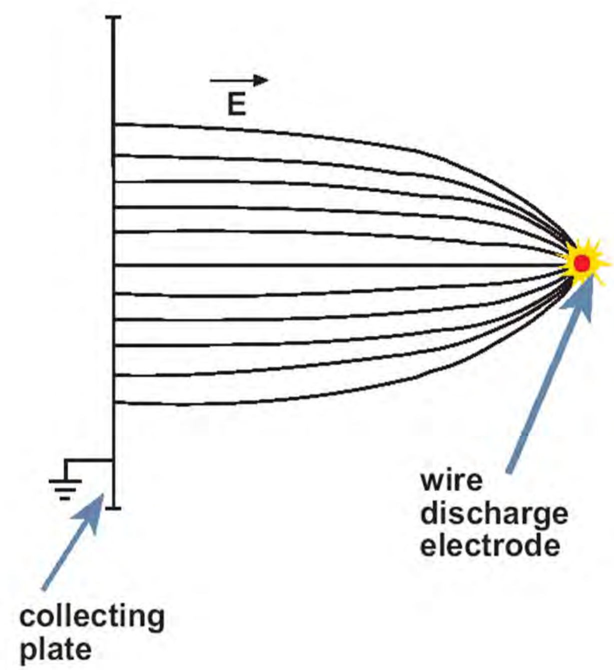
Dust emission vs. power consumption



Influence from fine particles

Poor Power Input





Fine grained dust increases the Space Charge Effect,

i.e. Corona Quenching

Topics

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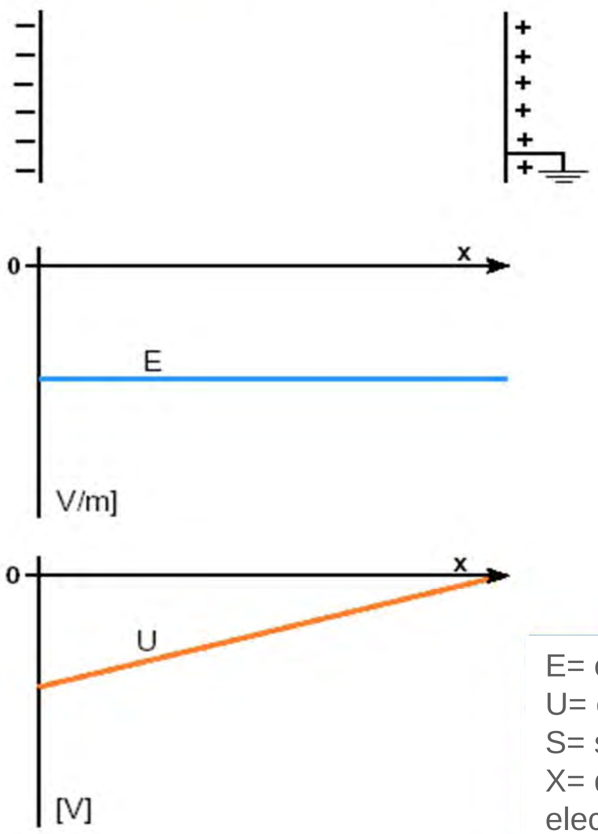
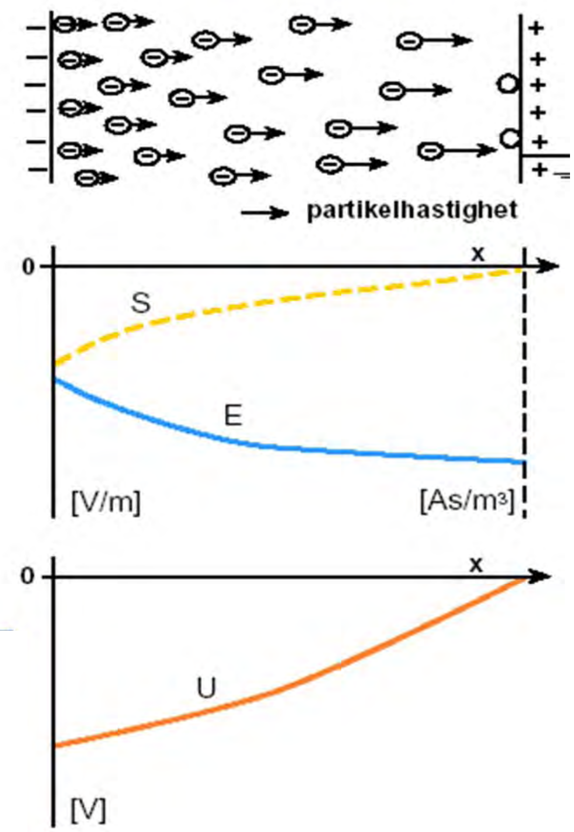
The space charge effect

No space charge

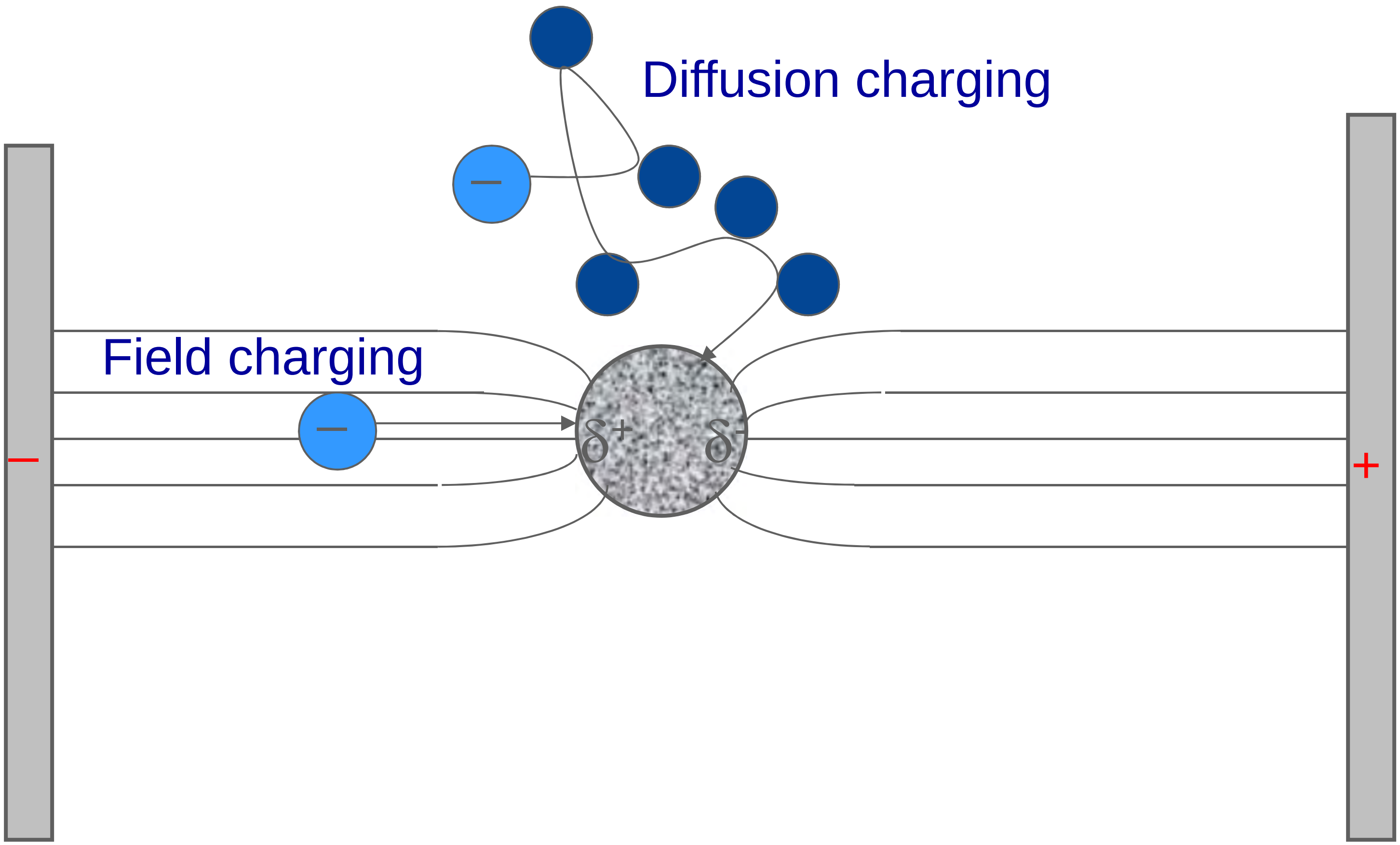


Space charge



E= electric field strength [V/m]
U= electric potential [V]
S= space charge [As/m^3]
X= distance from emission electrode [m]

Particle charging mechanisms



Particle charging mechanisms, n_s and t_0

Saturation Charge n_s and Charging Time Constant t_0 for the Field-Dependent Charging Process

E_0, kv/cm	a, μ	n_s	K, cm/sec/ volt/cm	N_0, ions/cm^3	t_0, sec
1	0.1	2	1	10^7	0.2
10	0.1	20	1	10^8	0.02
1	1.0	2×10^2	1	10^9	0.002
10	1.0	2×10^3	10	10^7	0.02
1	10.0	2×10^4	10	10^8	0.002
10	10.0	2×10^5	10	10^9	0.0002

Particle Charge for Diffusion Charging Process

t, sec / a, μ	10^{-3}	10^{-2}	10^{-1}	1	10
0.1	0.7	3	7	11	15
1.0	31	70	110	150	190
10	700	1100	1500	1900	2300
100	11000	15000	19000	23000	27000

’Industrial Electrostatic Precipitation’,
Harry J. White, 1963

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Particle charging mechanisms, n_s and t_0

Diffusion charging

- Dominating for small particles < 1u
- Low saturation charge, n_s
- High time constant, t_0

Field charging

- Dominating for particles > 1u
- High saturation charge, n_s
- Low time constant, t_0

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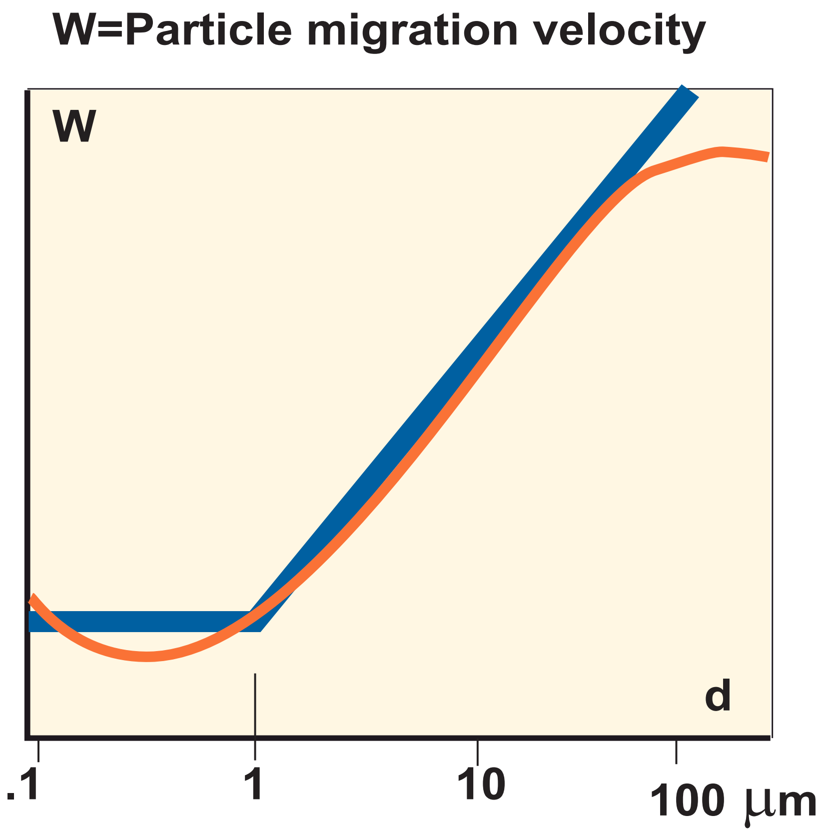
Migration velocity vs particle size

The impact on ESP efficiency from particle size



’Electrostatic Precipitators for Industrial Applications’, Porle, Francis, Bradburn, 2005

ESP, general

The space charge effect - Corona suppression

Space charge is essential for dust collection in an ESP, but may form a bottleneck if the space charge forces the voltage up to levels where the corona is limited by sparking: Corona suppression.

Hence:
Space charge is required while corona suppression/ is a term describing a situation where more corona power would be beneficial.

Space charge often is a challenge for ESPs after power boilers burning PRB blends, Kraft recovery boilers, some cement kilns etc, i.e. fine dust.

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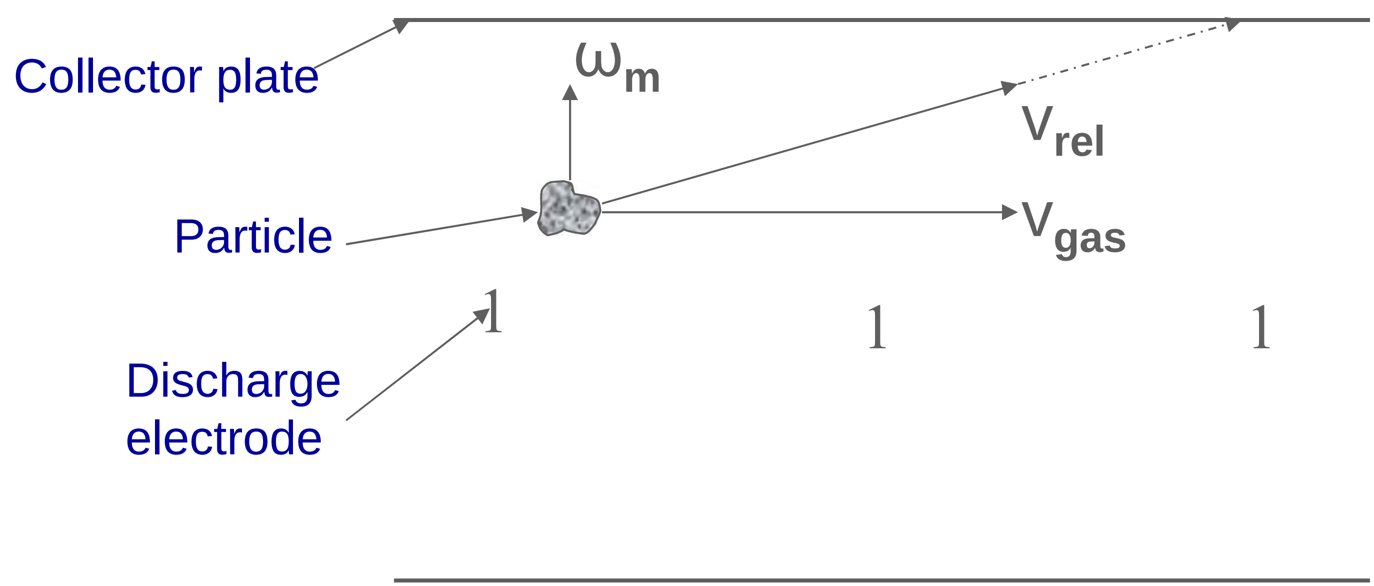
ESP, general

Migration velocity



ω_m = Velocity caused by the electrical field

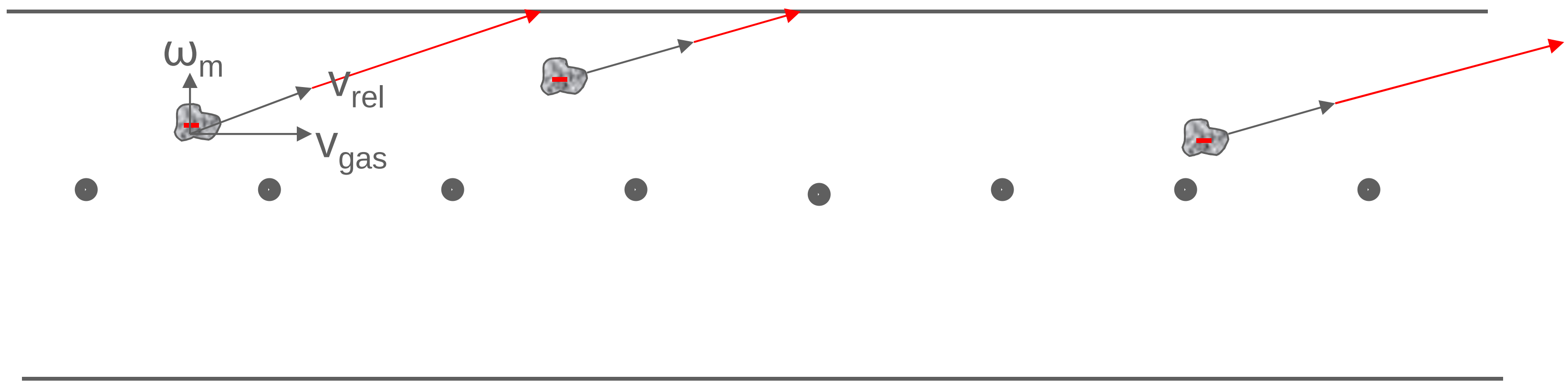
v_{gas}= Velocity caused by the gas

V_{rel} = Resulting velocity in the ESP

(As fine particles have a longer charging time**,** they will face a lower Vrel meaning that they more are prone to leave the ESP without being collected.)

ESP, general

Effect on velocity vectors from slow charging of the particle

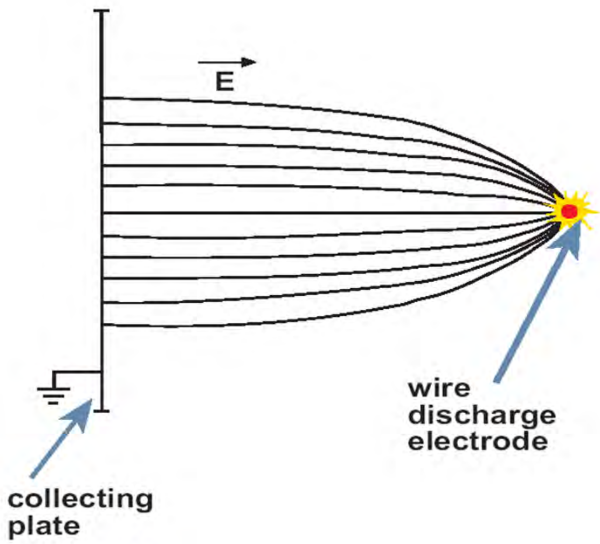


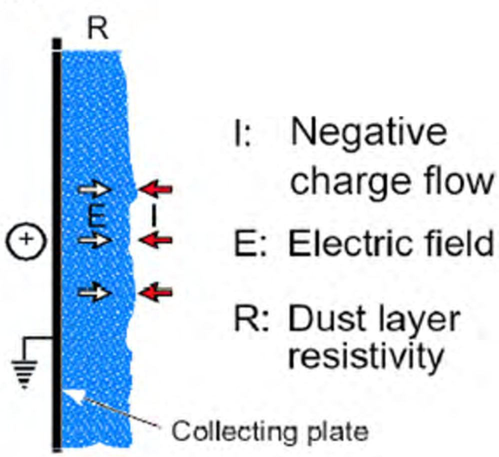
If the charging of the particle takes a long time (small particle < 5 um), the particle may leave the ESP before reaching the collector electrode.

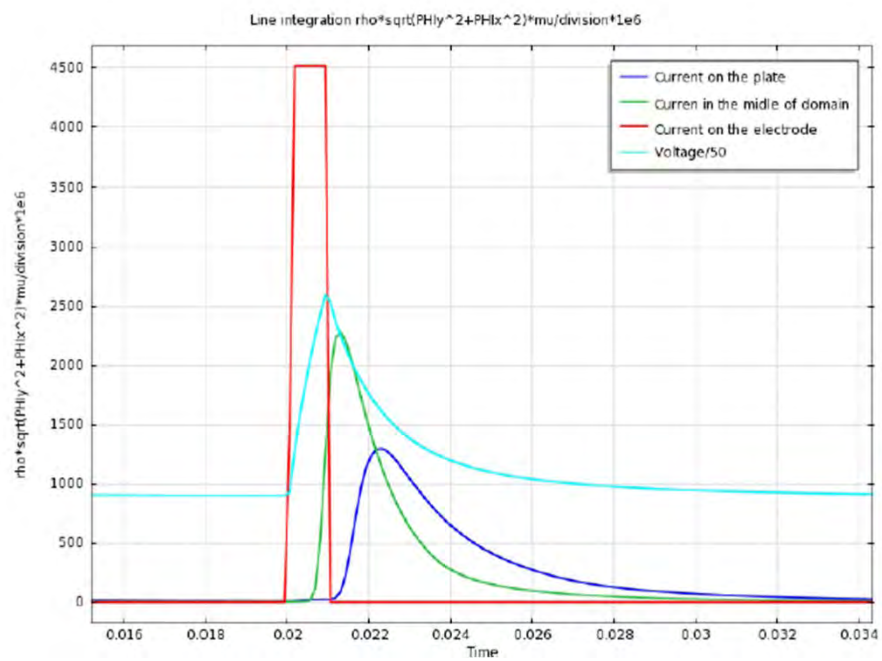
For this type of particle a higher current density is required for good efficiency..

Dust where this has a notable impact is typically soda recovery boilers but it is also found for power boilers burning PRB blends or several export coals from South-Africa or South-America.

Gas region and dust-layer







Electrostatic force:

$$F = Q \cdot E$$

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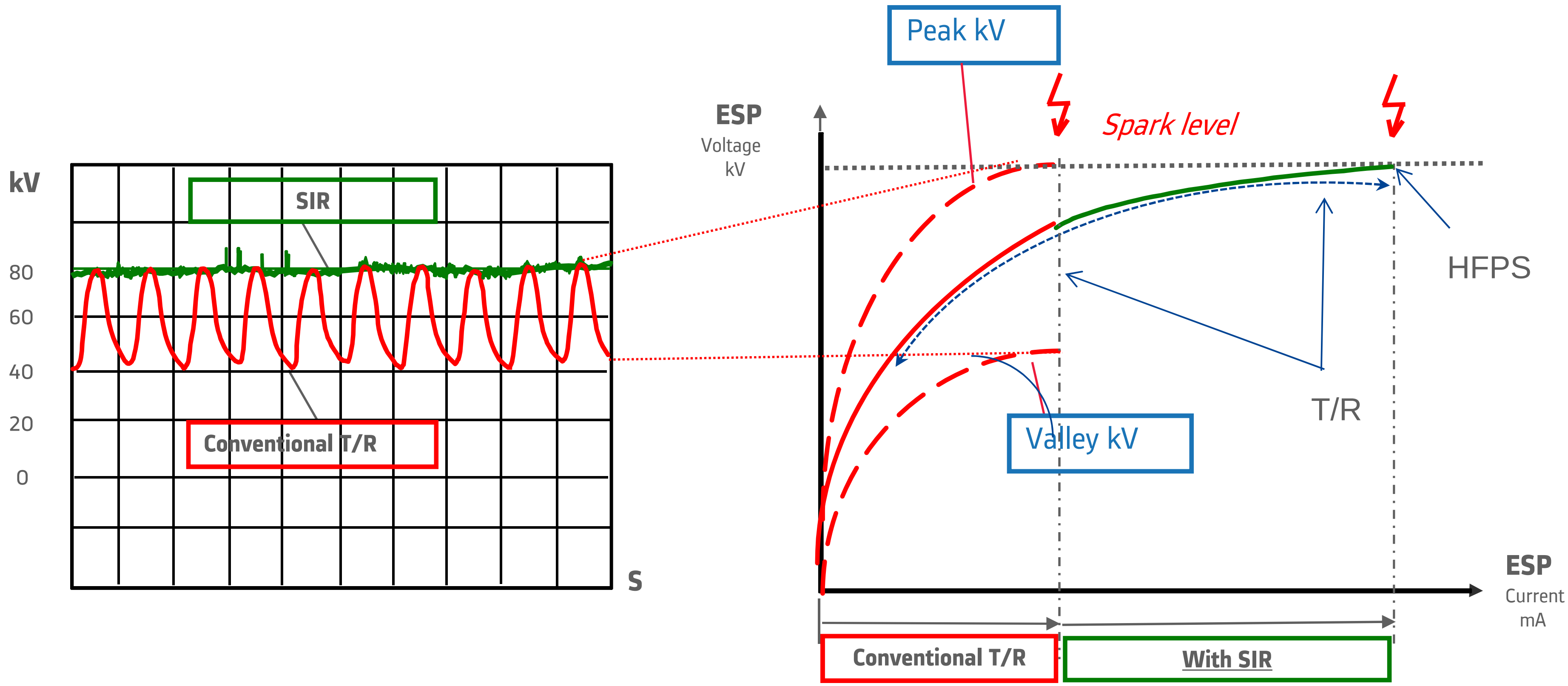
HFPS vs. Conventional T/R
Electrical Performance – Output Voltage



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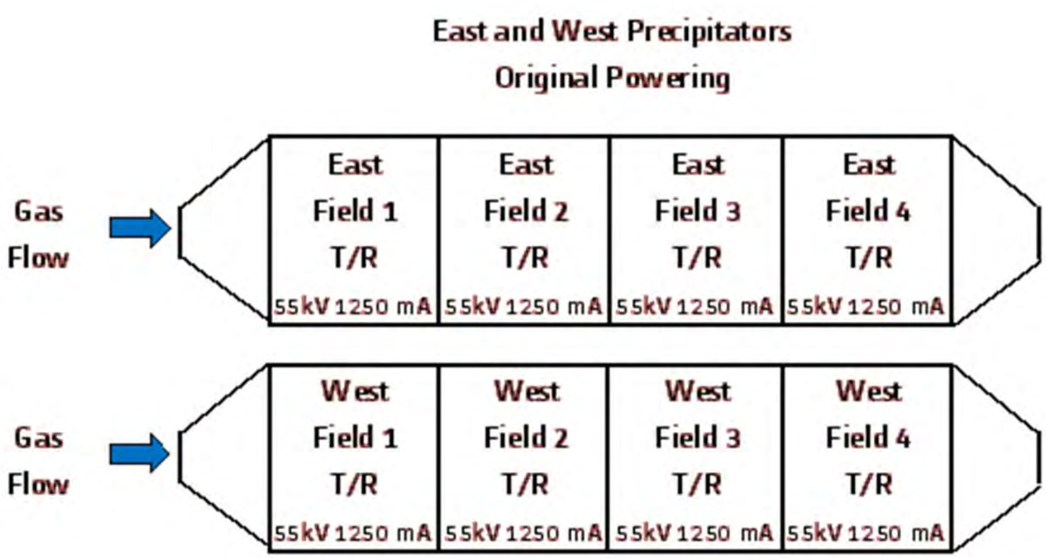
Upgrade of a Soda Recovery ESP



Soda recovery boiler in Maine USA.

ESP has two casings each with four bus-sections.

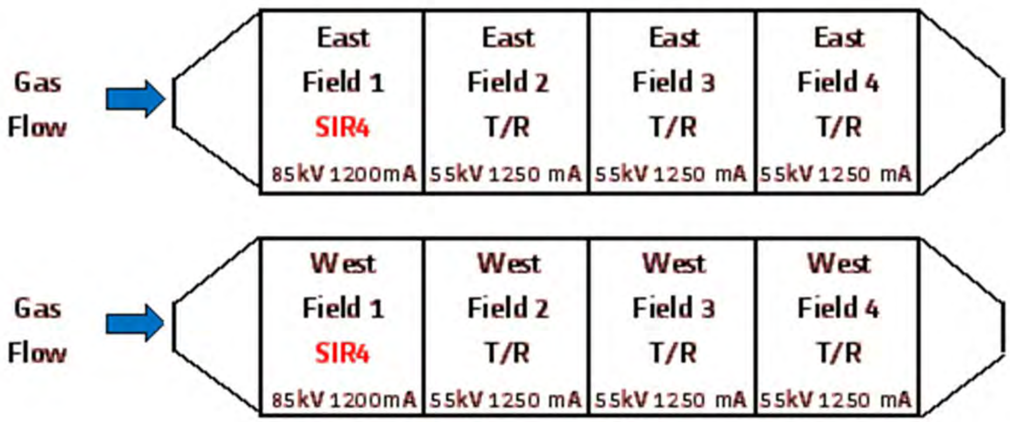
Operation was limited by opacity (at 20%).

High Frequency Power Supplies installed at entry fields to address the Corona Quenching.

Upgrade of a Soda Recovery ESP

Installation of HFPS, SIR4, 85/1200, at entry field

East and West Precipitators
Powering With SIR 4



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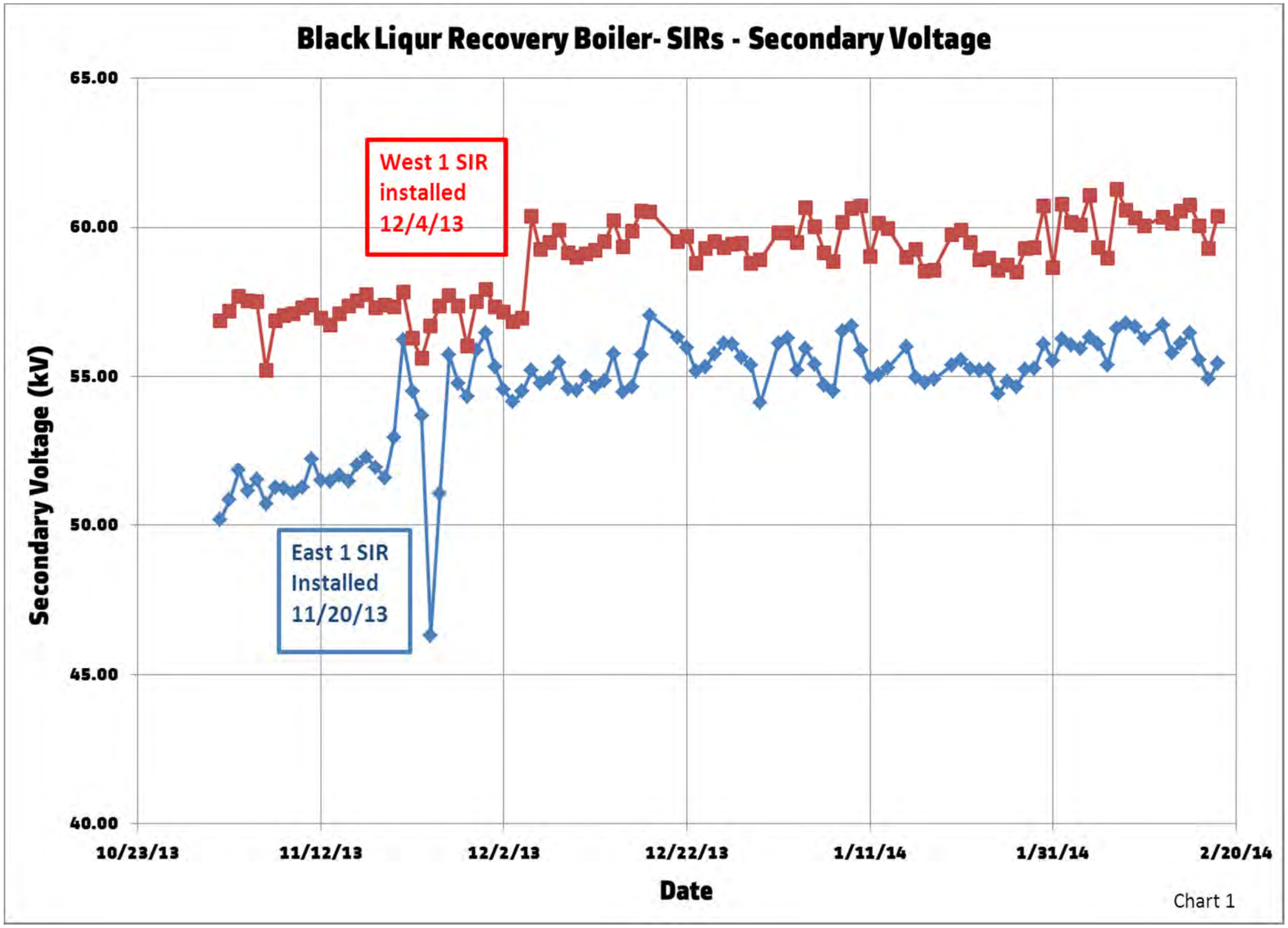
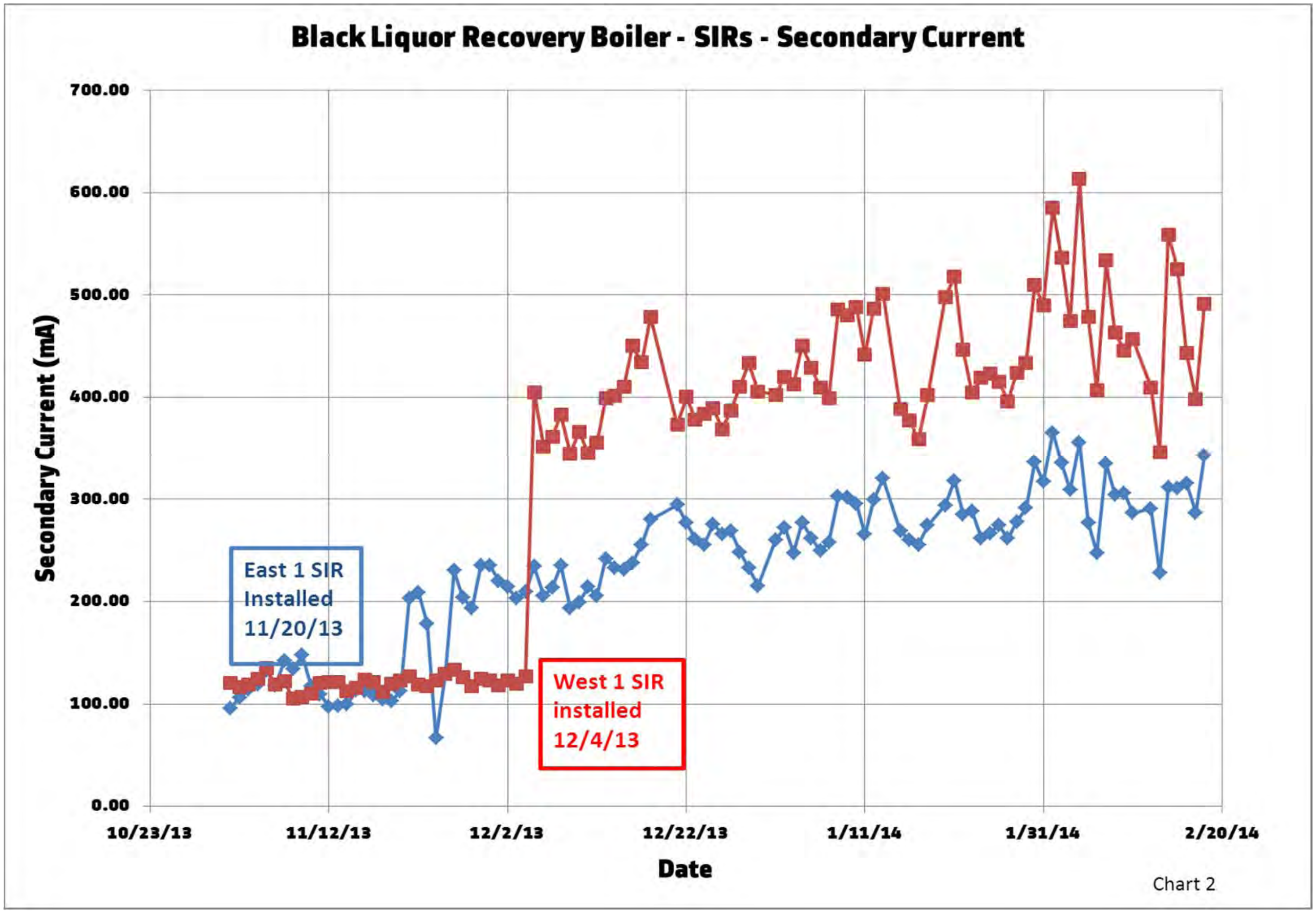
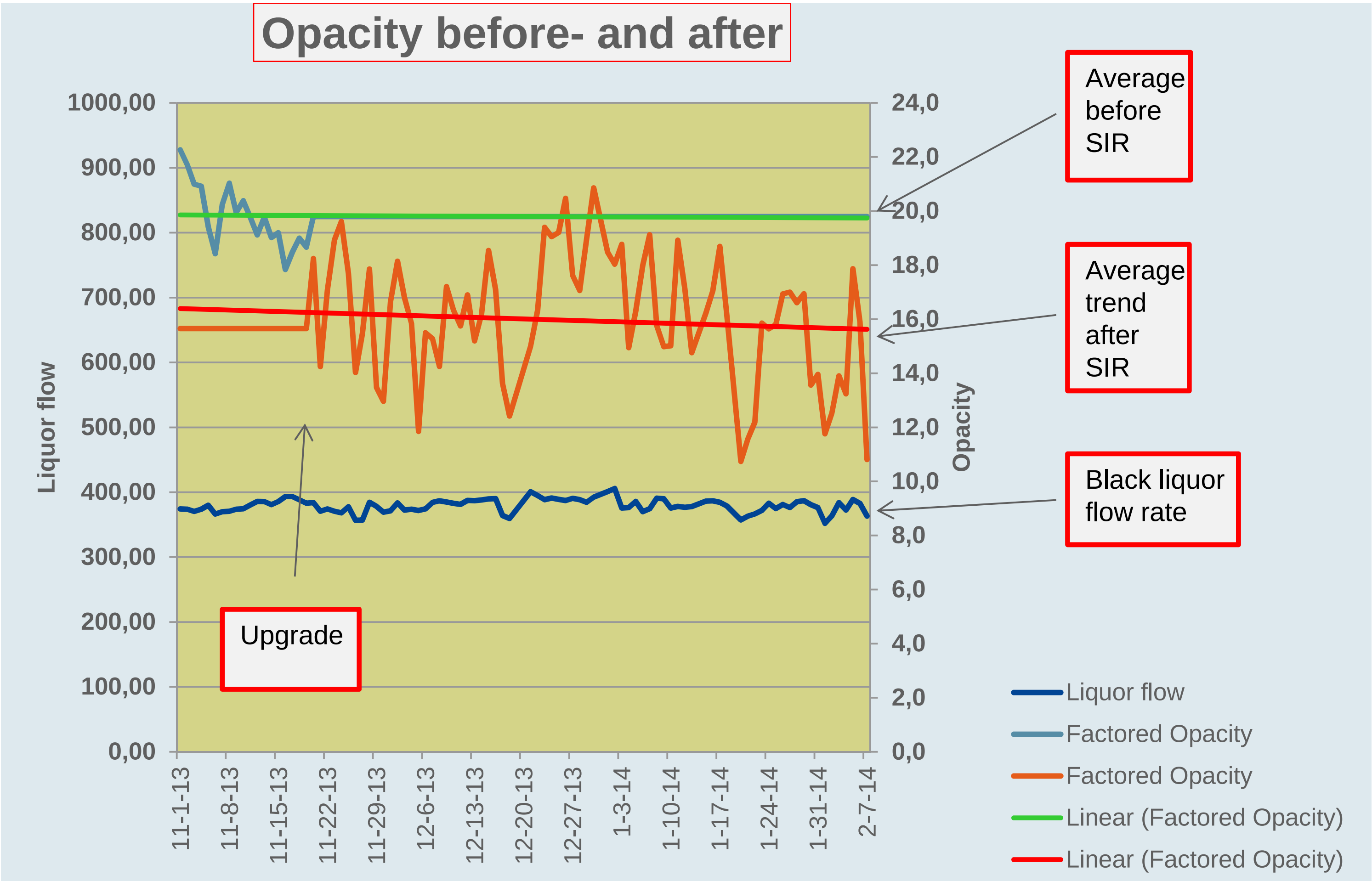
Impact on ESP voltage from upgrade



Impact on corona current from upgrade



Impact on stack opacity from entry field upgrade



Kuusankoski, Soda Recovery boiler ESP

Summary of test campaign:

-Three-field precipitator, field 1&2 with HFPS (SIR) and conv. T/R-set

-Arrangement to quickly (seconds) alternate power source

-Outlet emissions measured by a gravimetrical method,
(isokinetic kinetic dust sampling)

-Electrical data logged during tests

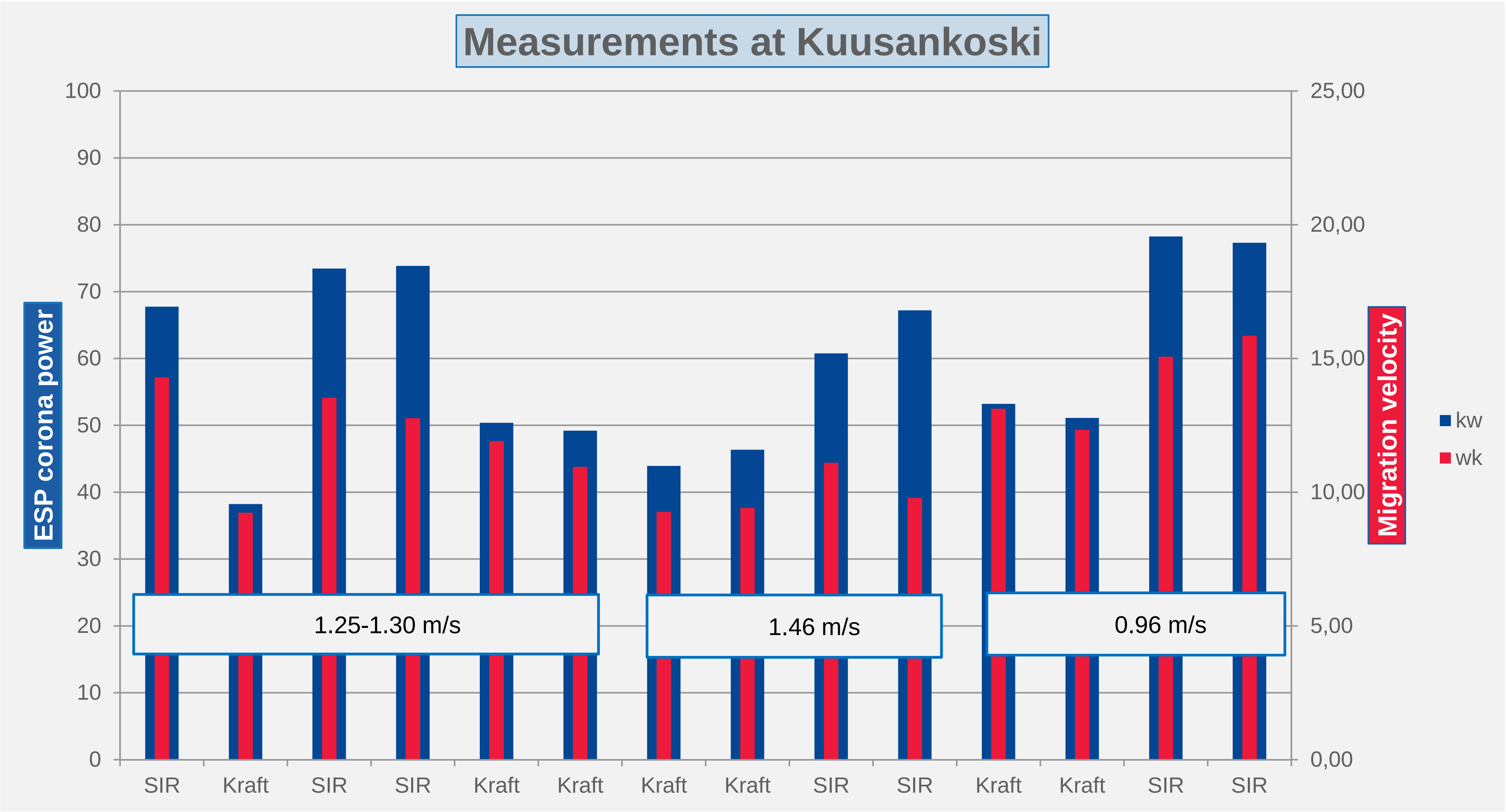
-A sequence of 14 different tests was conducted

Alternating power sources, SIR and T/R-set

Gas velocity 0.96 – 1.45 m/s

- Evaluation by $\omega_{k,}$ (Matts-Ohnfelt)

Kuusankoski, kW vs ω_k (migration velocity)



Kuusankoski, kW vs migration velocity

Average secondary power	SIR	71.2 kW
	T/R	47.5 kW
Average migration velocity	SIR	13.2 cm/s
	T/R	10.0 cm/s

30 % increased ω_k means smaller ESP, more cost effective solution

Kuusankoski, impact on size

Project	Example			
Ref	June 27 2014			
Process	Coal fired boiler			
Type of plai	Pulverised coal			
			Design	SIR
Design data				
AP	Gas flow	Actual m^3/s	471,0	471,0
BE	Gas tempera	C	130,0	130,0
CV	Flue gas mo	% by volume	10,9	10,9
DD	Inlet dust conc. Dry		12,0	12,0
EB	Barometric p	mmHg	725	725
EP	Static pressu	Pa	-666	-666
Efficiency		%	99,82	99,81
ESPsize				
Casings			2	2
Chambers			2	2
Cells			1	1
Fields			4	4
L	Field length	dm	45	45
W	Cell width	dm	72	72
H	Height	dm	150,00	115,30
Spacing		mm	400	400
No of passes			18	18
Area/bus section		m^2	2430	1868
No of bus sections			16	16
Total area		**m^2**	**38880**	**29886**
Total area (H)		m^2	51840	39848
A/Q(H)		$m^2/m^3/s$	110,06	84,60
Velocity		m/s	1,09	1,42
Selected expected Wk (H-spacing)			**36,00**	**46,80**
Migration vel improvement				1,3
K			6,29	6,29
Expected particulate			**22,2**	**22,2**

The test results point at a migration velocity improvement of 30%, which is applied.

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Tests at Pego Power, Portugal

2 units, each 315 MW
3 mills on S-A coal
1 mill on Colombia coal
2*16 T/R sets
Emission 25-50 mg/Nm^3
Design 110 mg/Nm^3
Space charge limited in entry fields due to high percentage of fines.

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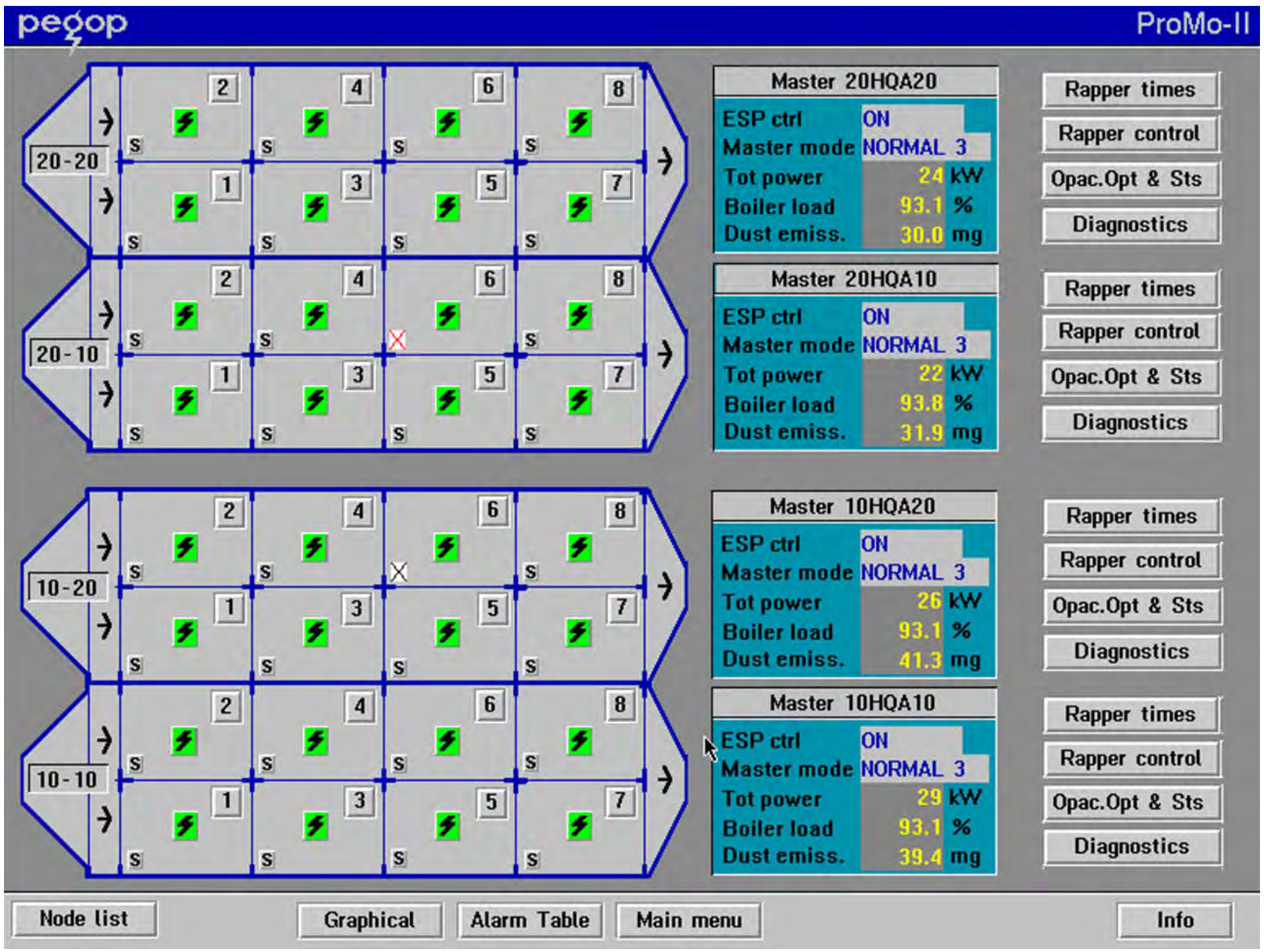
Tests at Pego Power Portugal, layout



View from the ESPs at Pego. The test pass (2, 4, 6 and 8 of 20-20) and the parallel pass forming one casing. Each unit has two casings forming one ESP.

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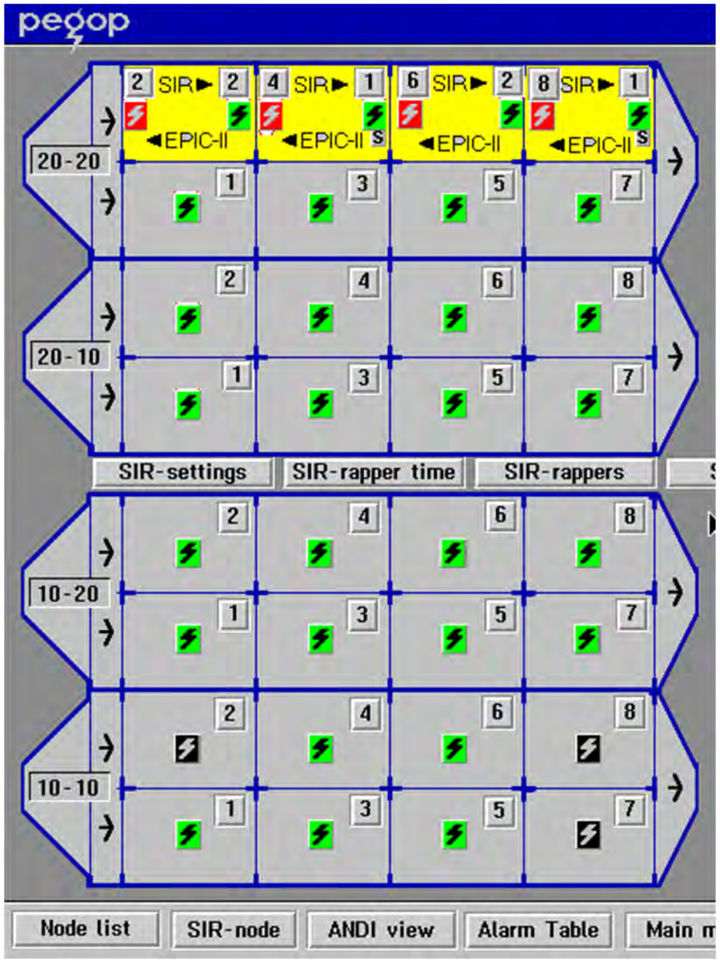
Tests at Pego Power, Portugal



The T/R controllers with even numbers starting at 40 were replaced by SIRs.

The main difference was that with HFPS it was possible to double the first field current thus simplifying for all down-stream sections.

The doubling was possible due to the SIRs being able to operate closer to the spark over voltage having a lower ripple.

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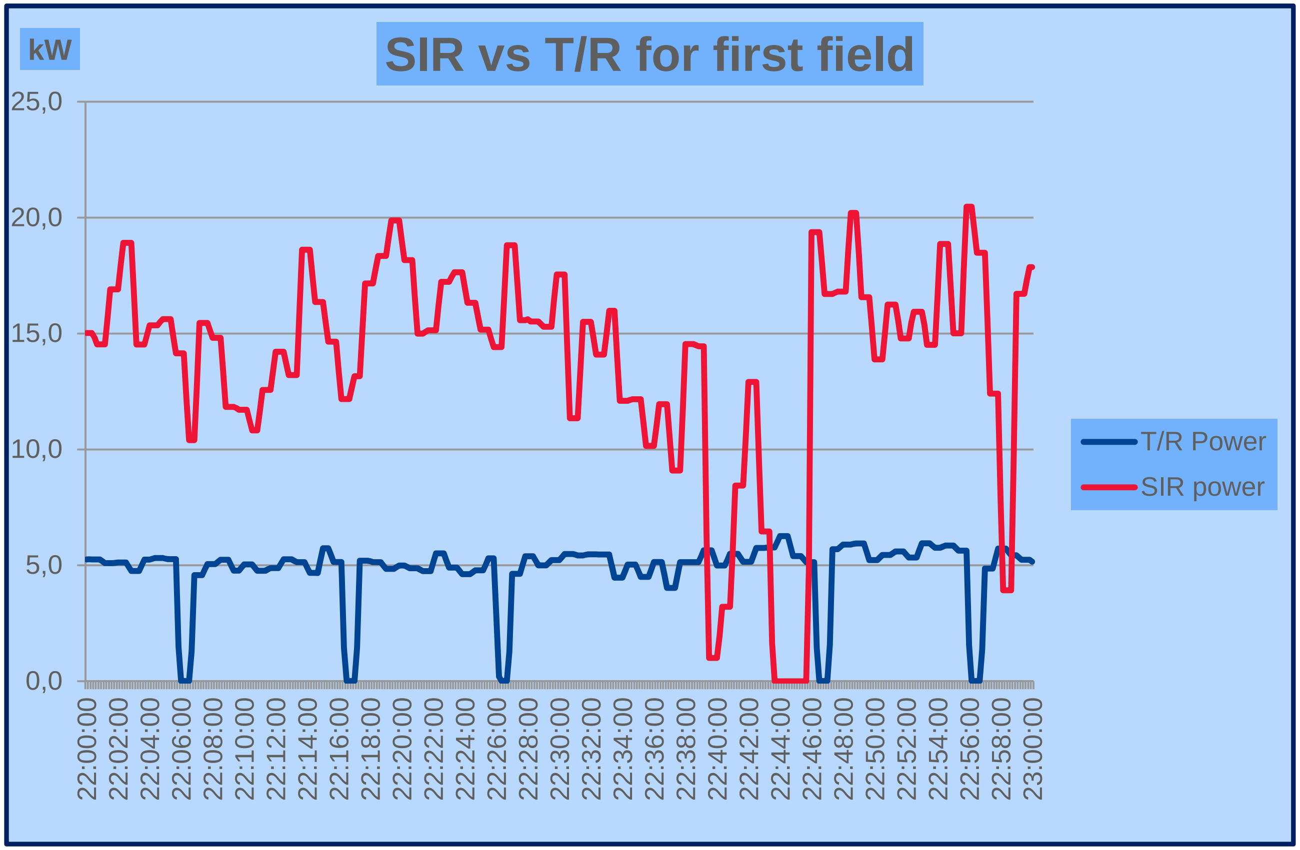
Tests at Pego Power Portugal, Corona Quenching



Note how the current drops and recovers after the Power Off Rapping.
When operating close to the maximum voltage proper cleaning of the electrodes is essential

Upgrade at Pego Power Portugal

- HFPS (SIR) in field 1&2 to address Corona Quenching (SCR and low NOx burners)
- Outlet emission before upgrade 25-50 mg/Nm^3
- Outlet emission after upgrade 5-15 mg/Nm^3
- Total reduction of emission ≈2/3

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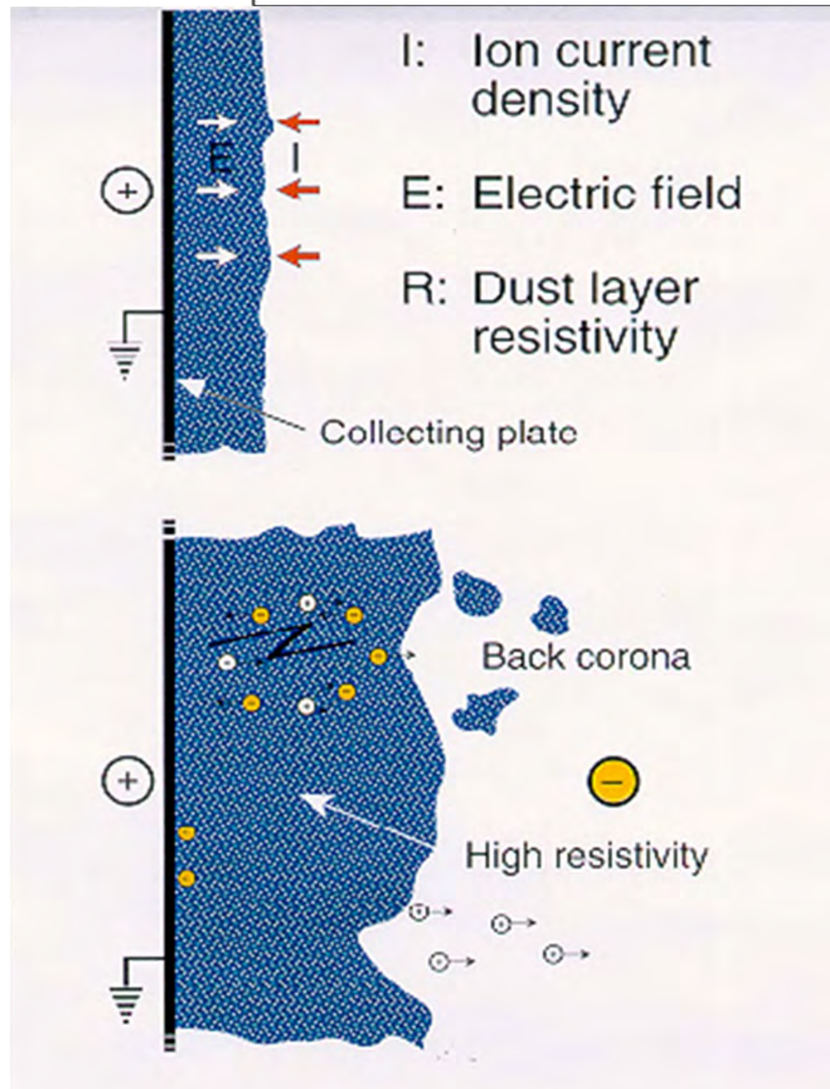
Back-Corona and Re-entrainment

$$E = j\,\rho$$

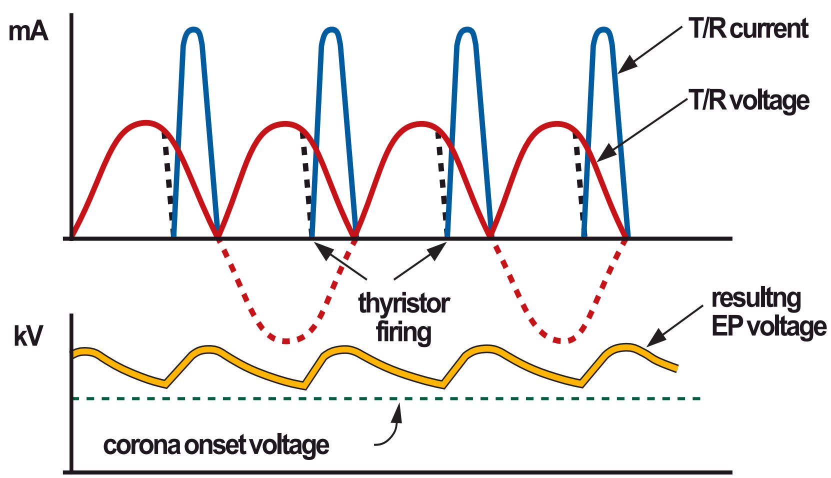
$$F = EQ$$

E *Field strength,* [V/m]
j *Current density,* [A/m^2]
ρ *Dust layer resistivity,* [Ωm]
Q Charge, [As]

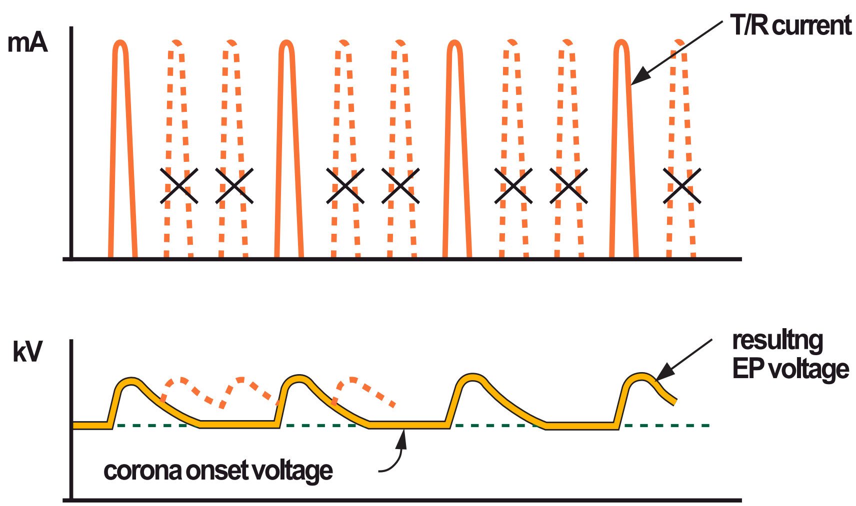


Semipulse on conv. T/Rs

Conventional full wave T/R operation



Semi-pulsed T/R operation



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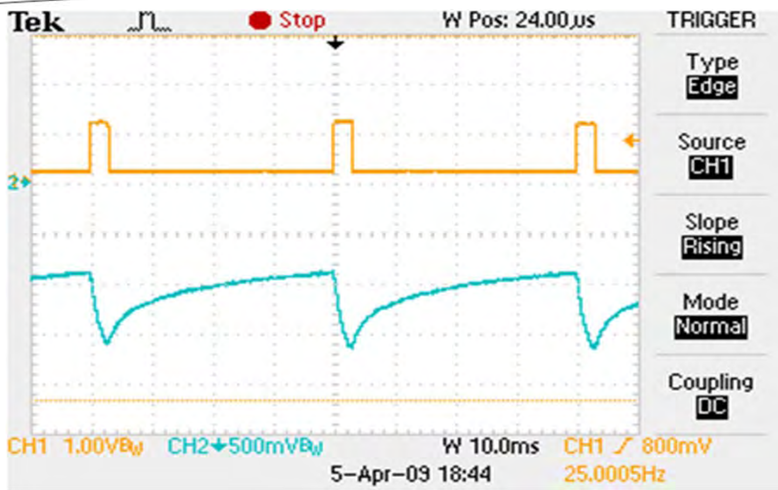
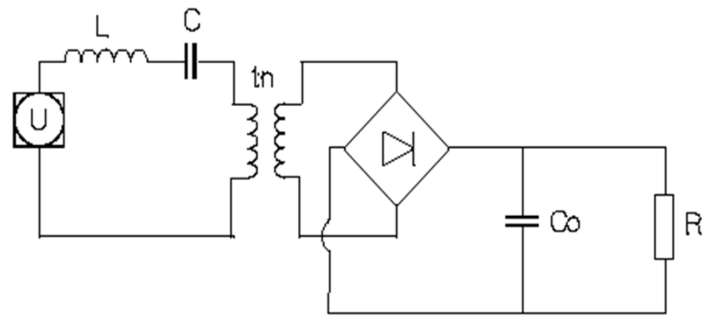
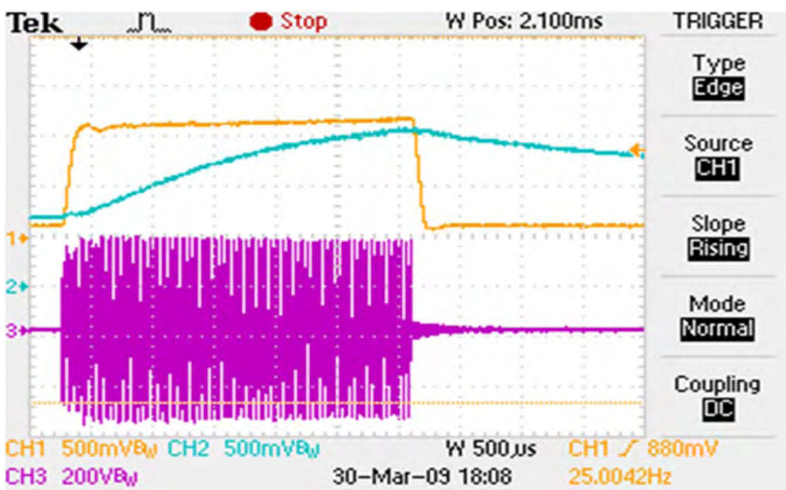
Intermittent energization, pulse mode



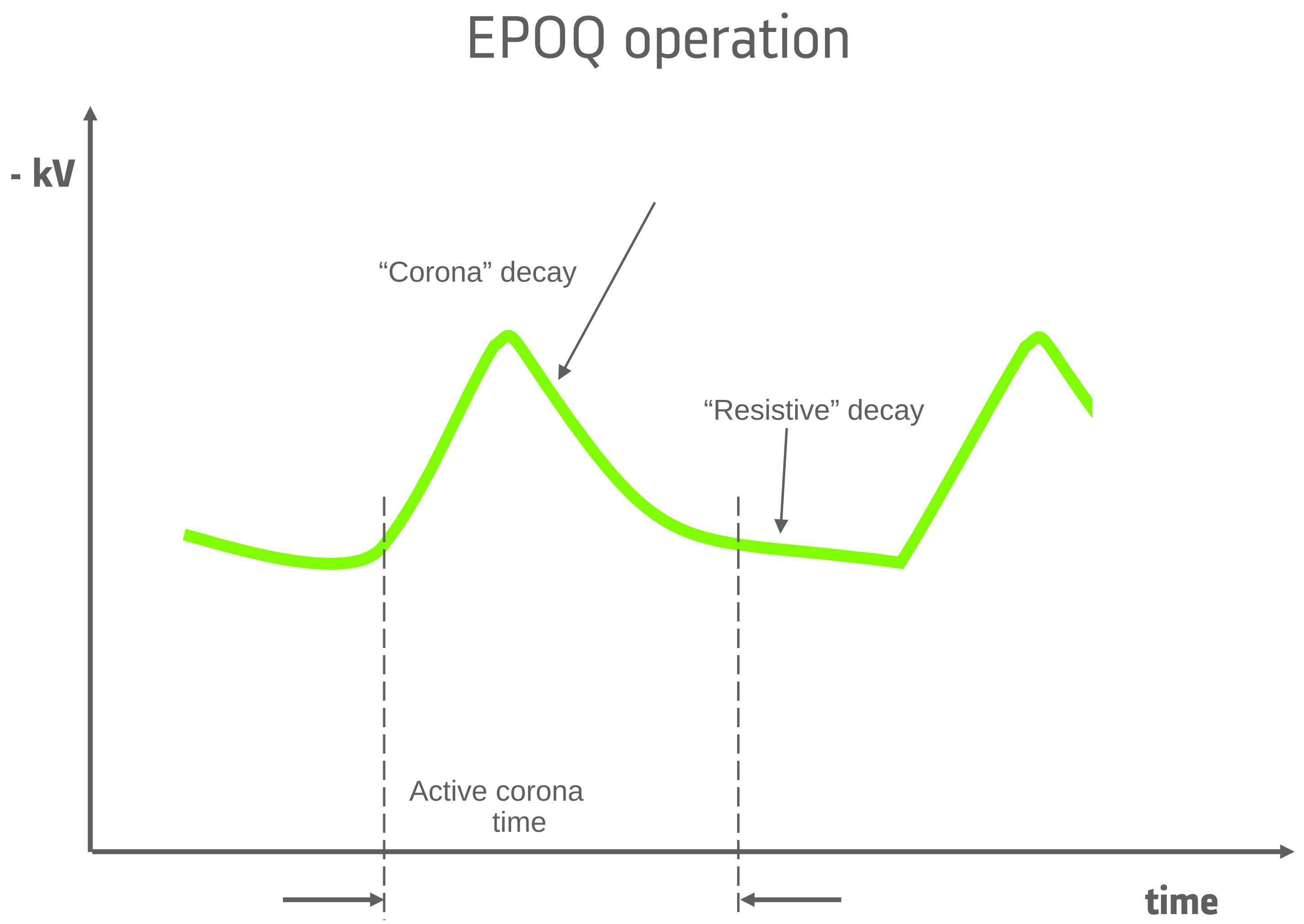
10ms/div





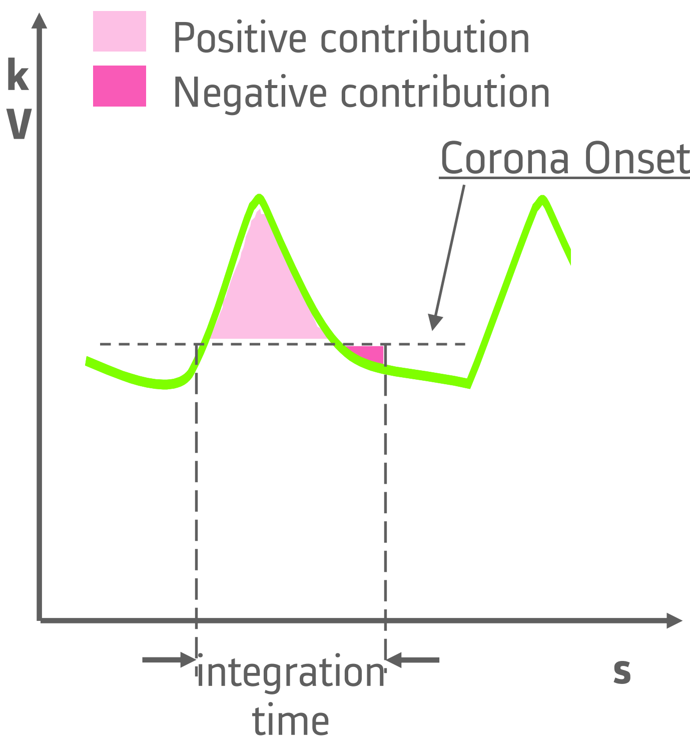
500us/div

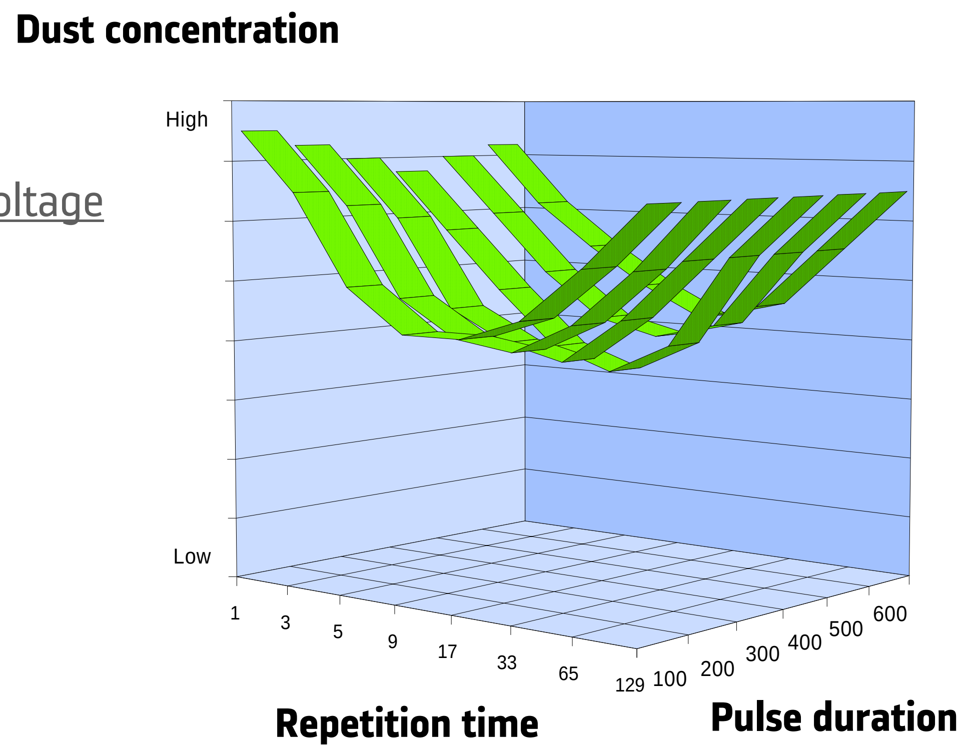
EPOQ principle of operation



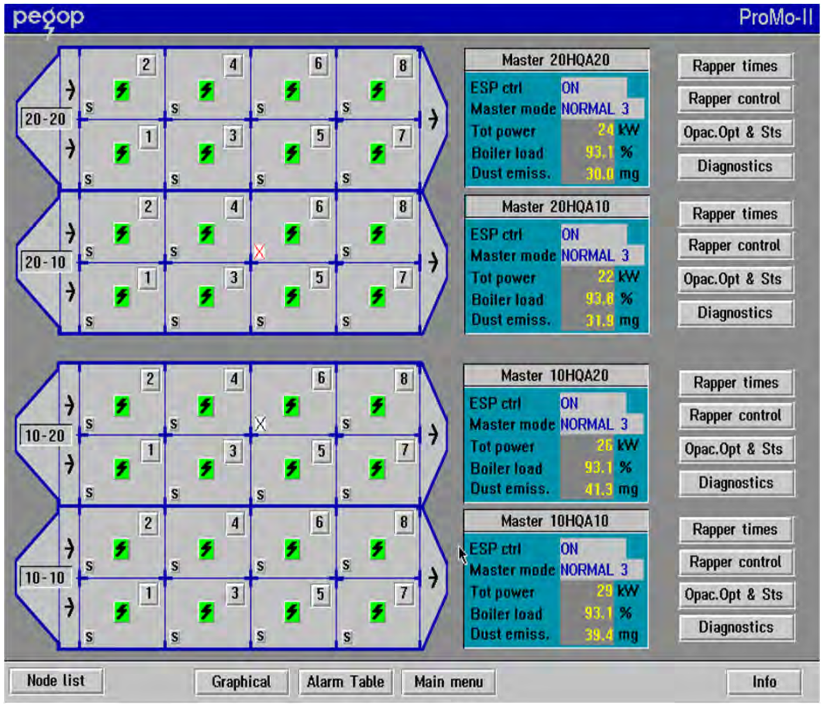
Pulse optimization

EPOQ operation





Sensing Back Corona to Control FGC, injection of SO_3



The ESP is used as a sensor to measure the amount of back-corona. The injection rate is adjusted (Sulphic) to control (closed loop) the amount of back-corona.

EPOQ, pulse mode optimization software, in EPICs/SIRs reacts to the amount of back-corona in each bus-section by optimizing pulse mode parameters, pulsing and pulse current limit, in order to minimize emission.

The optimized pulse parameter settings from each EPIC/SIR are weighted and summed by the Sulphic. The resulting value reflects the actual back-corona condition. This together with boiler load signal is used to control the SO3 injection rate, increase/decrease.

- Optimized SO_3 dosing, follows changing op. Conditions
- Reduced SO_3 injection
- Minimized negative effects from over dosing

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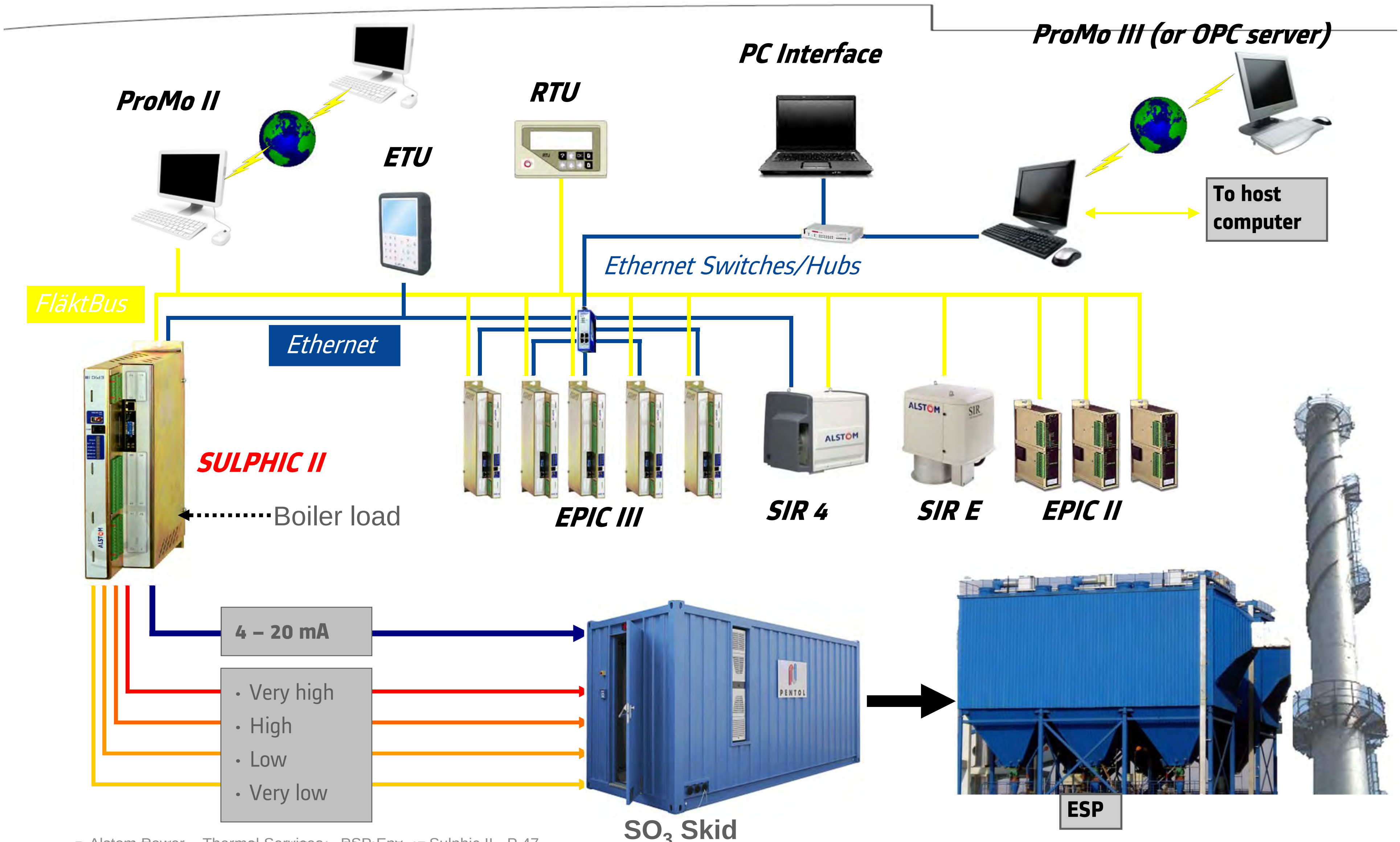
Sulphic II, control system



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Summary

- Corona quenching due to space charge effects results in reduced corona current and collecting efficiency. Well known from fine dust, low resistivity applications.
  - HFPS in entry field improves collection of fine dust and make downstream fields also to improve efficiency
  - Applies also to high resistivity power applications. observed on PRB, SA and Columbian export coals

- A method to automatically control the SO_3 injection rate is presented. The ESP is used to sense the back-corona status, which is used to control the injection rate.
  - Optimized SO_3 usage
  - Avoid negative effects from overdosing

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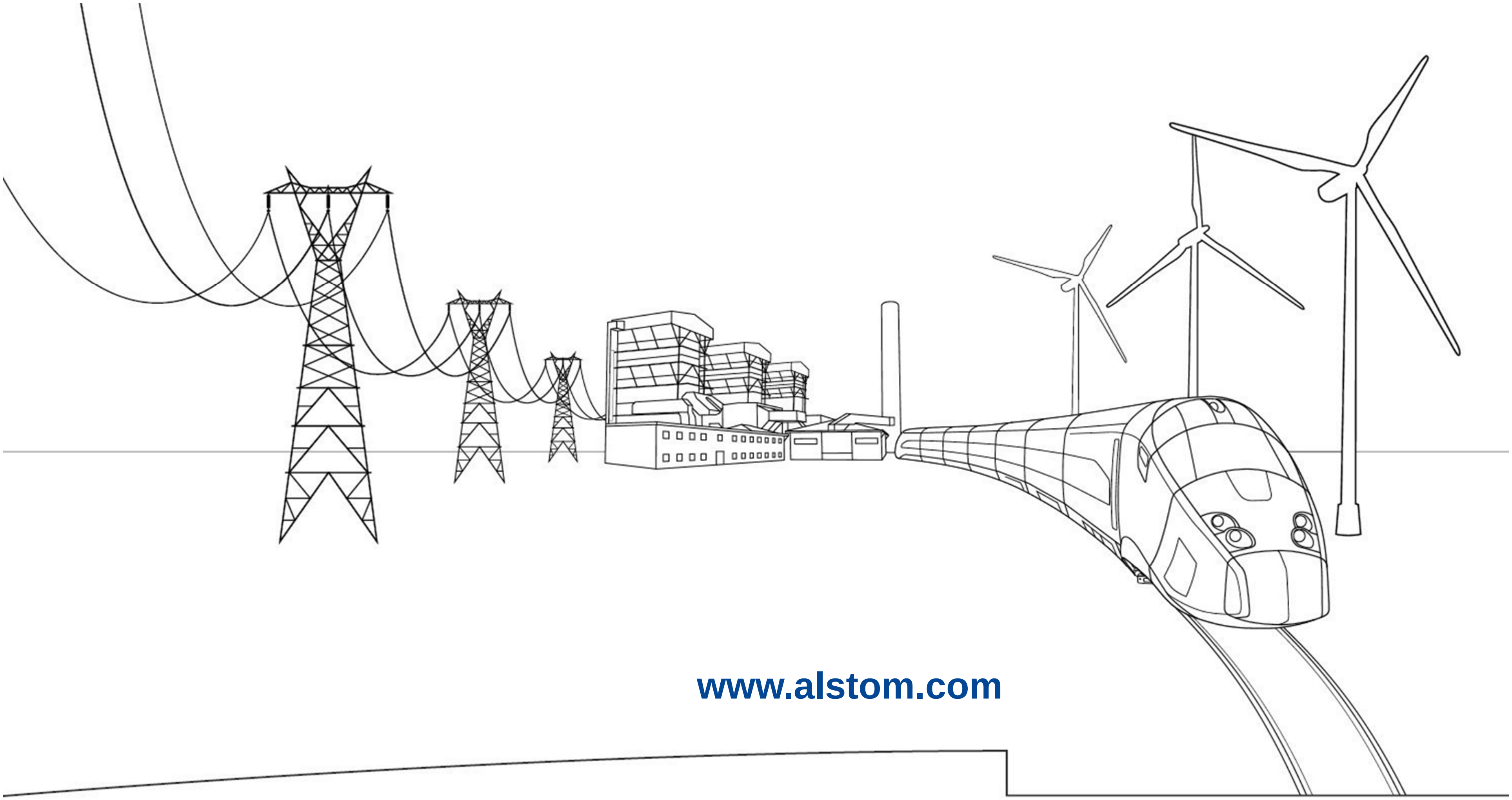

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Shaping the future