

REINHOLD ENVIRONMENTAL Ltd.



2016 APC-Wastewater Round Table & Expo Presentation

July 18 & 19, 2016 in Dearborn, MI / Hosted by DTE Energy

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A review of ESP power supplies

APC/Round Table 2016
Reinhold Environmental
Dearborn, MI, July 18th, 2016

Per Ranstad

Imagination at work

Outline

Introduction

ESP Power supplies:

Thyristor and T/R set based:

single phase, three phase

Inverter based:

High Frequency power supplies

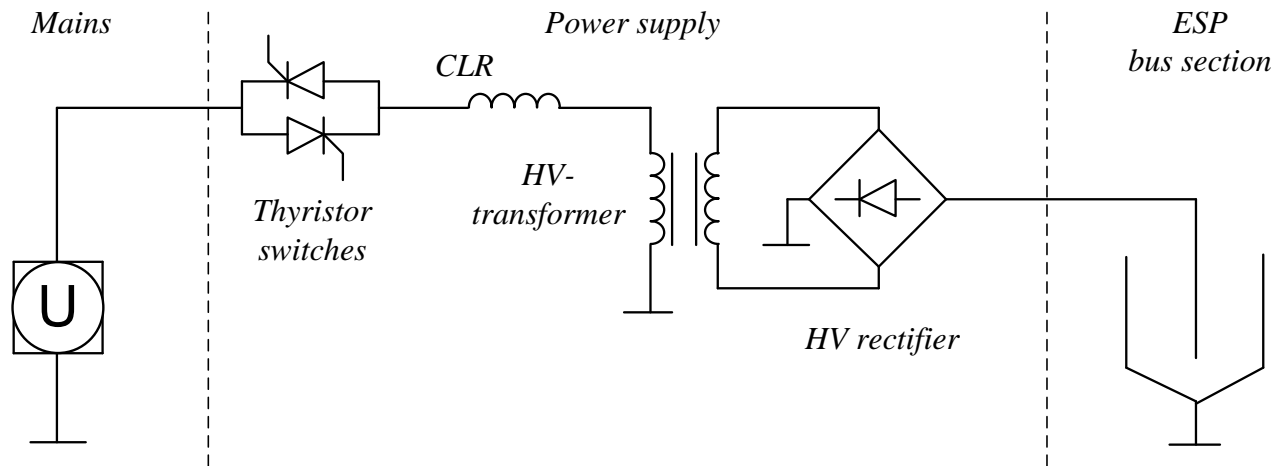
Mid frequency power supplies

Pulsed power supplies

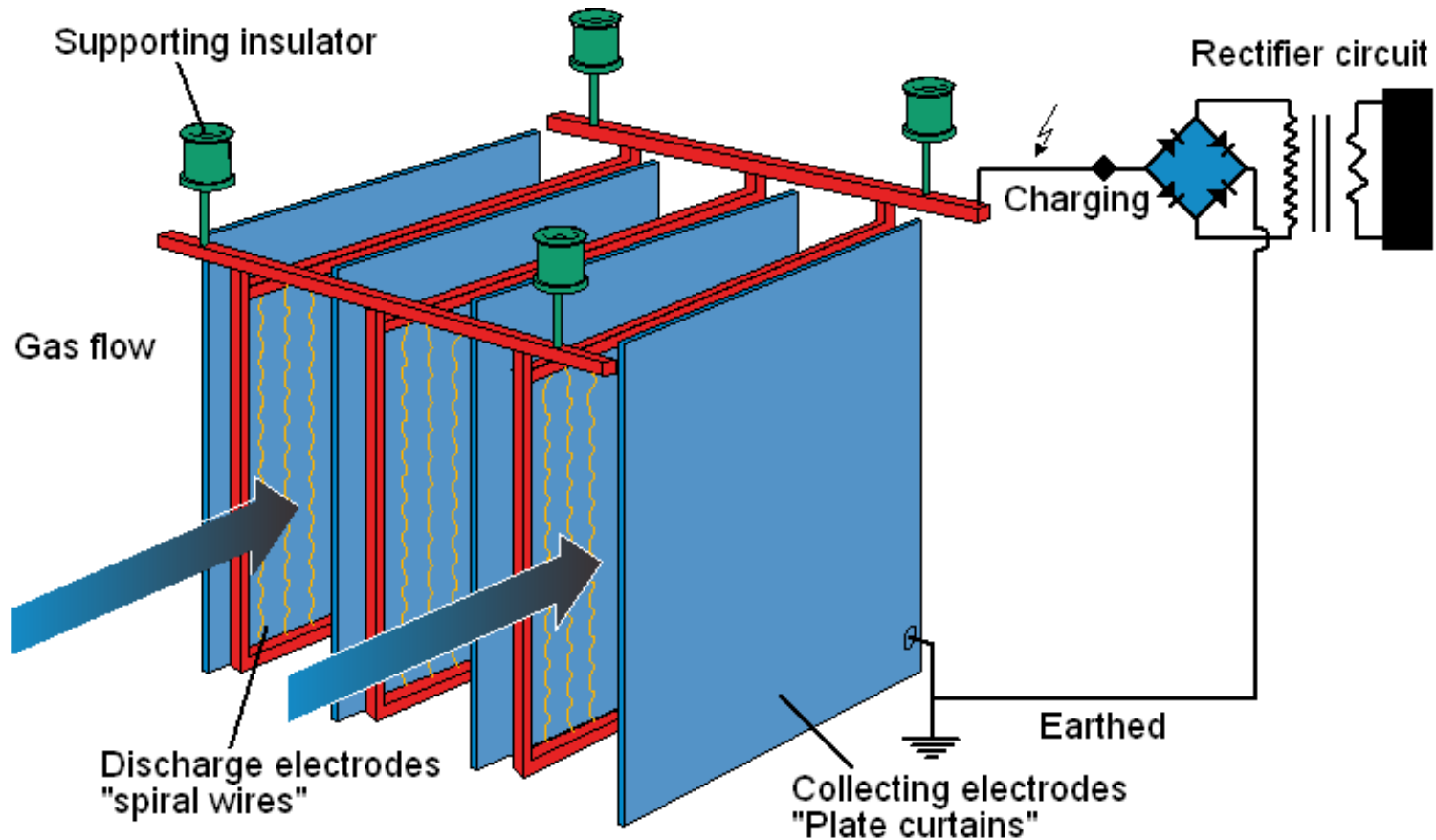
Discussion



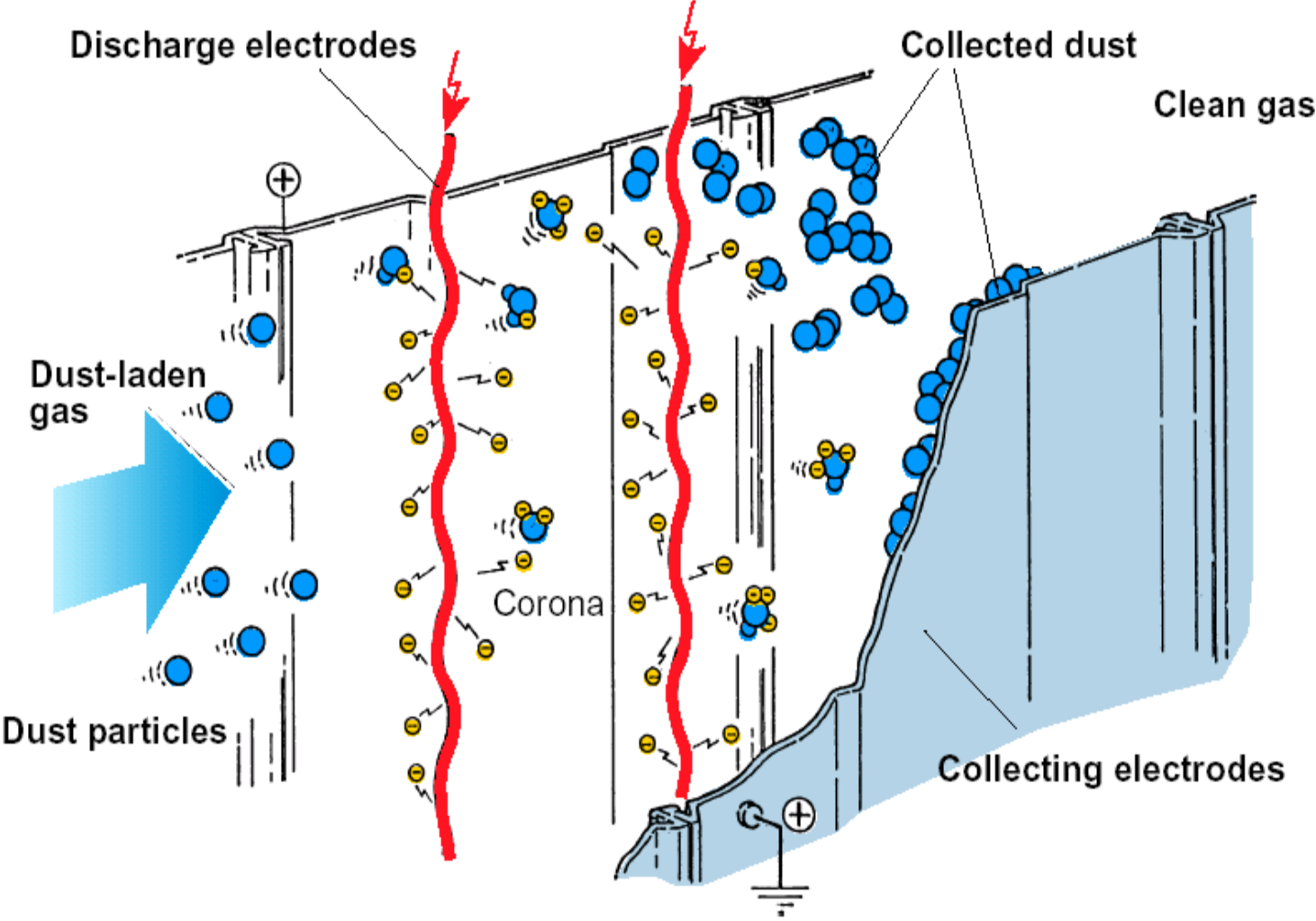
Some aspects on ESP power supplies



Principal design of Electrostatic Precipitator



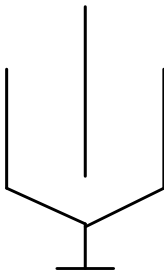
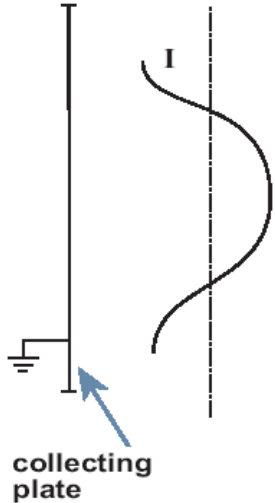
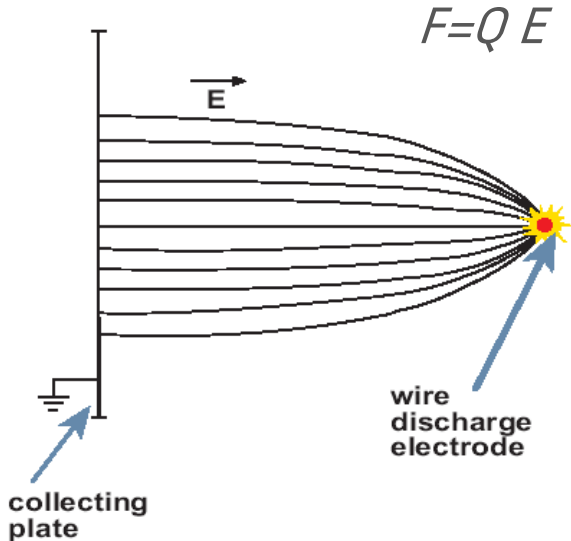
ESP dust collection



Electrical field, gas

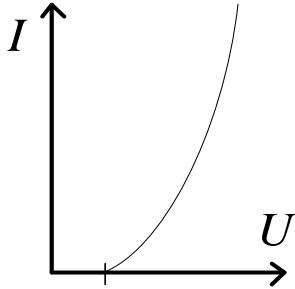
Field charging

Diffusion charging



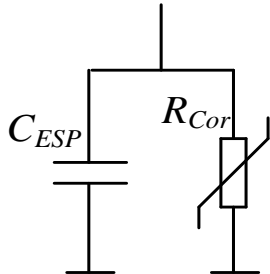
(a)

Bus-section



(b)

VI-curve

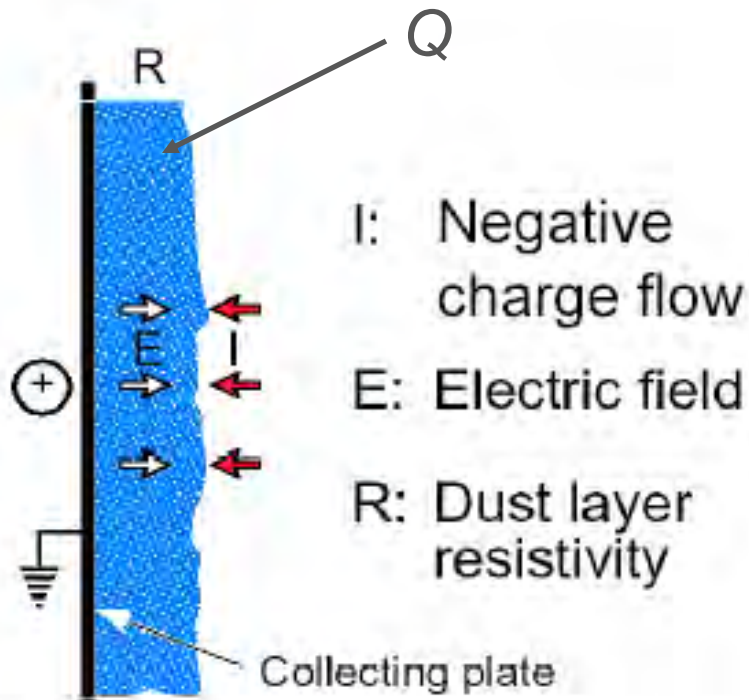


(c)

Circuit model ,RC



Dust layer, electrostatics



$$F = Q E$$

$$E = j \rho$$

$$\Rightarrow F = Q j \rho$$

F Force, [N]

Q Charge, [C, (As)]

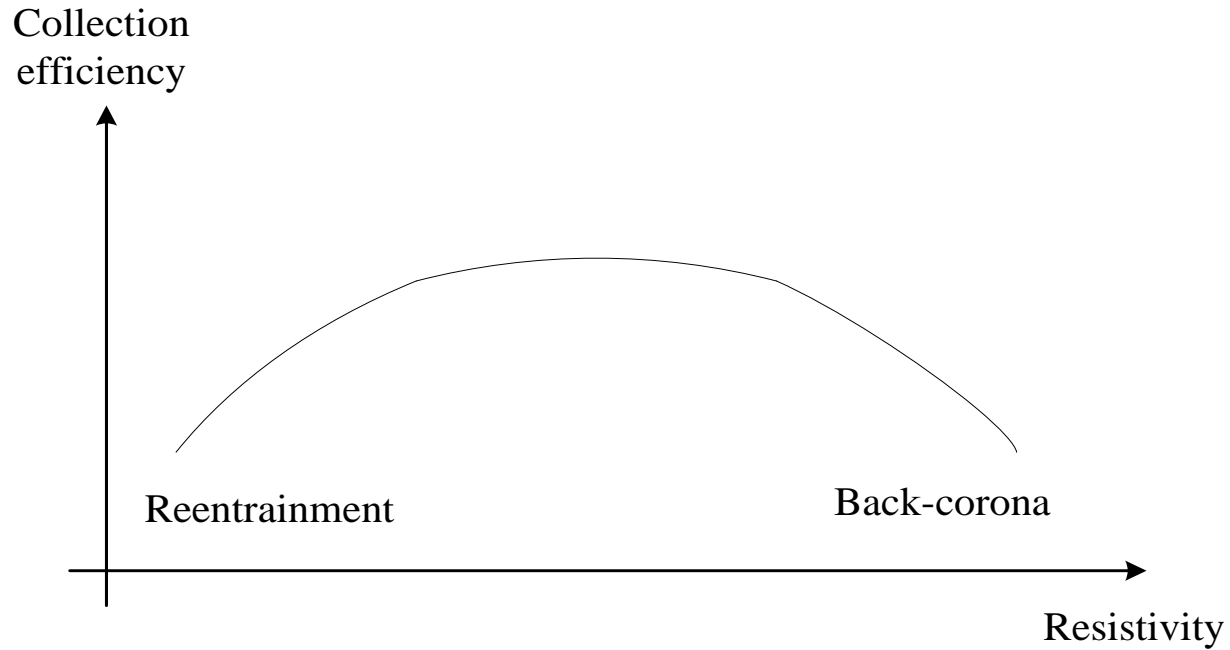
E Field strength, [V/m]

j Current density, [A/m²]

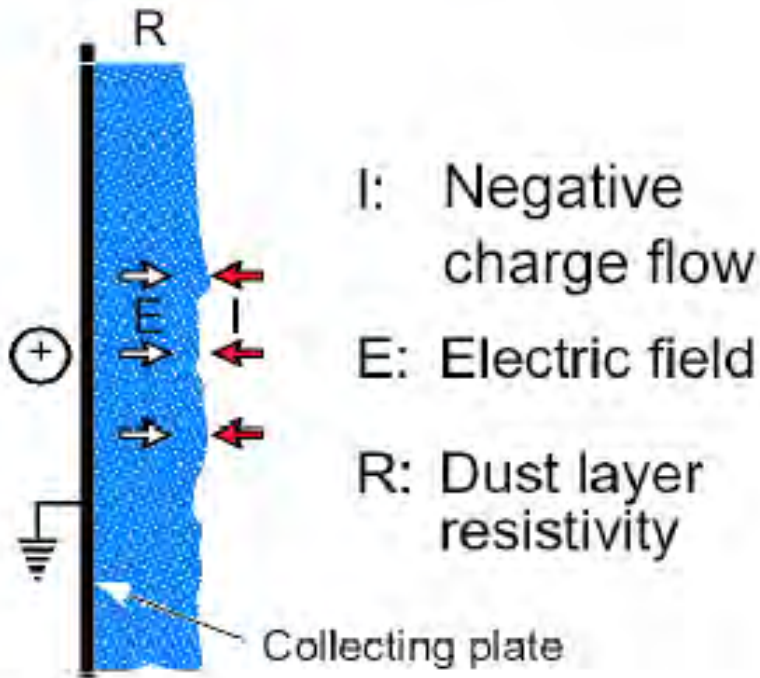
ρ Dust layer resistivity, [Ω m]



Dust emission vs. resistivity



Dust layer, resistivity



Classification 1

<i>Conductive</i>	$10^4-10^8 \Omega\text{cm}$
<i>Normal</i>	$10^8-10^{10} \Omega\text{cm}$
<i>Moderate</i>	$10^{10}-10^{11} \Omega\text{cm}$
<i>High</i>	$10^{11}-10^{13} \Omega\text{cm}$

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

Classification 2

<i>Low</i>	$10^7-10^9 \Omega\text{cm}$
<i>Best perf.</i>	$10^9-10^{11} \Omega\text{cm}$
<i>High</i>	$10^{11}-10^{13} \Omega\text{cm}$

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

Classification 3

<i>High</i>	$>10^{10} \Omega\text{cm}$
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[White, Industrial Electrostatic Precipitation, 1963]



Electrical effects

Sparking

Rapid discharge of bus-section

=> *No field, erosion*

Back Corona

High E-field in the dust layer, spark-over

=> Injection of positive charges into the gas

Re-entrainment

Low E-field in the dust layer

=> Reduced holding forces in the dust layer

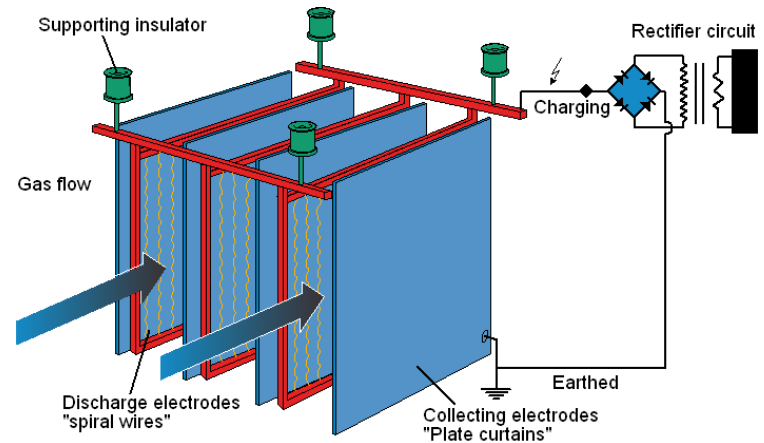
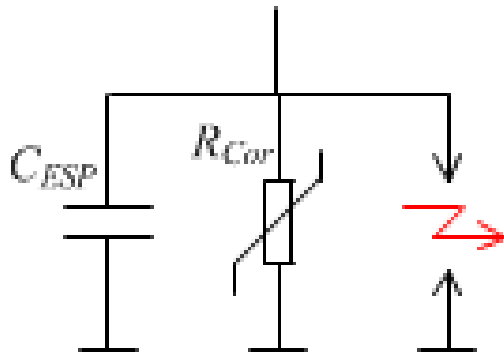
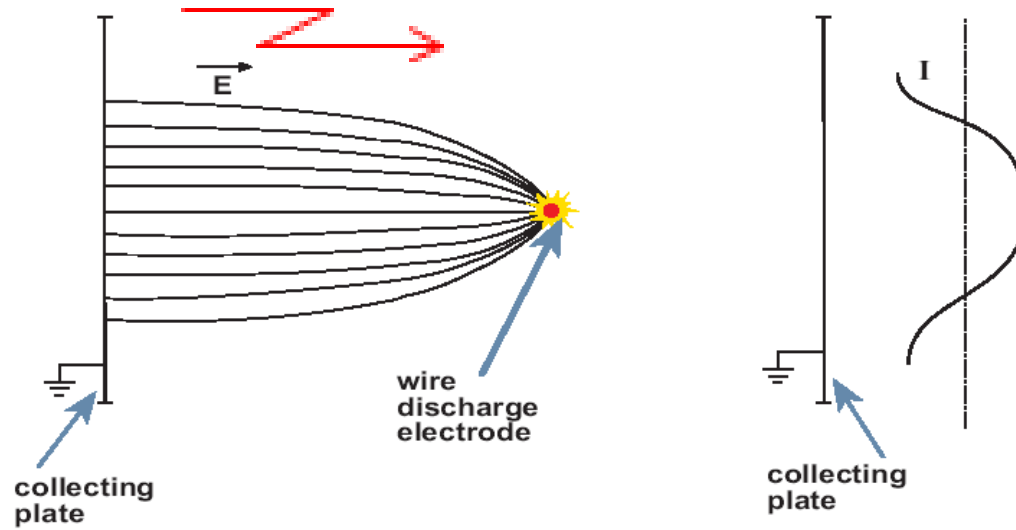
Corona quenching

Reduced E-field at the emitting electrode

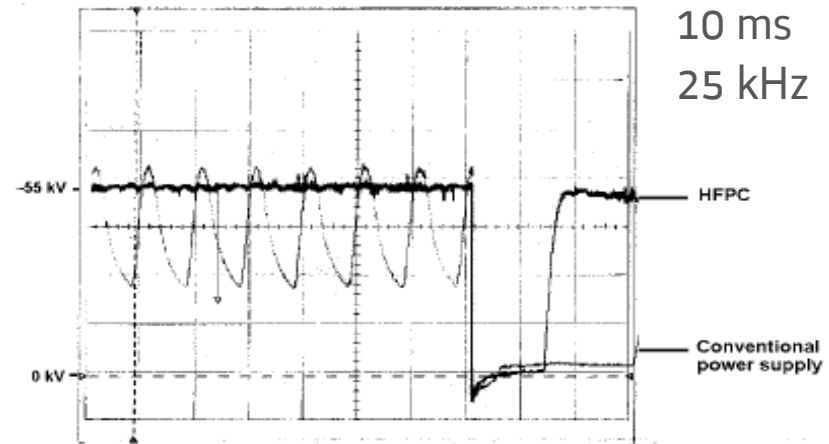
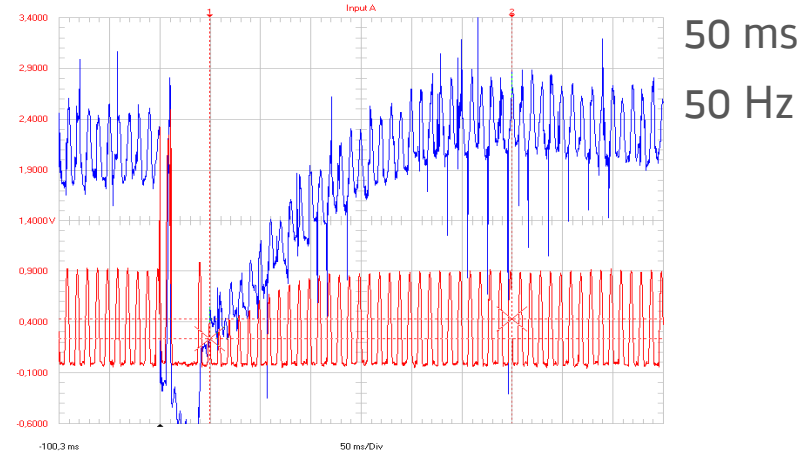
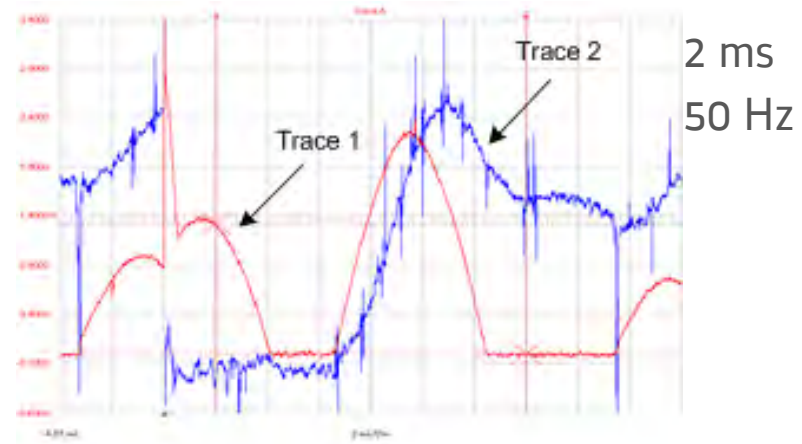
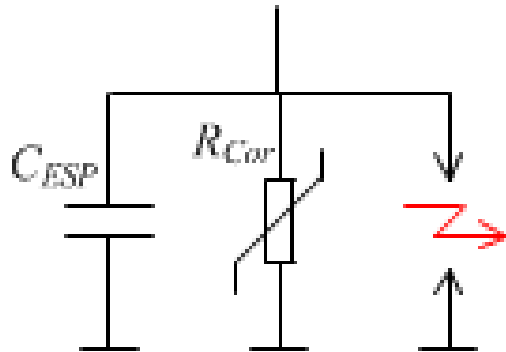
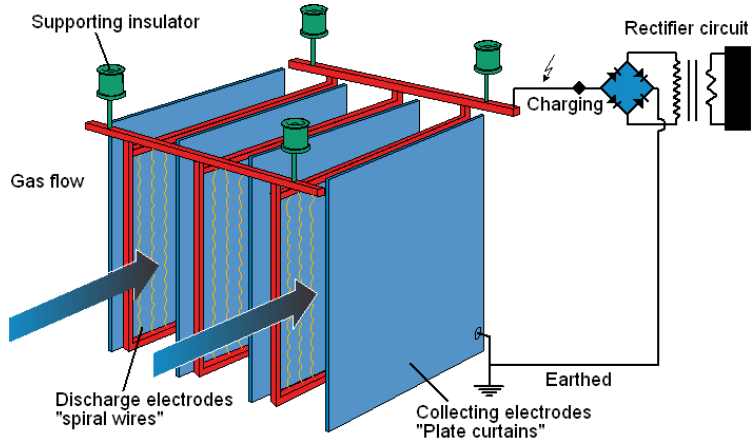
=> *Less Corona current*



Sparking, gas



Sparking, gas



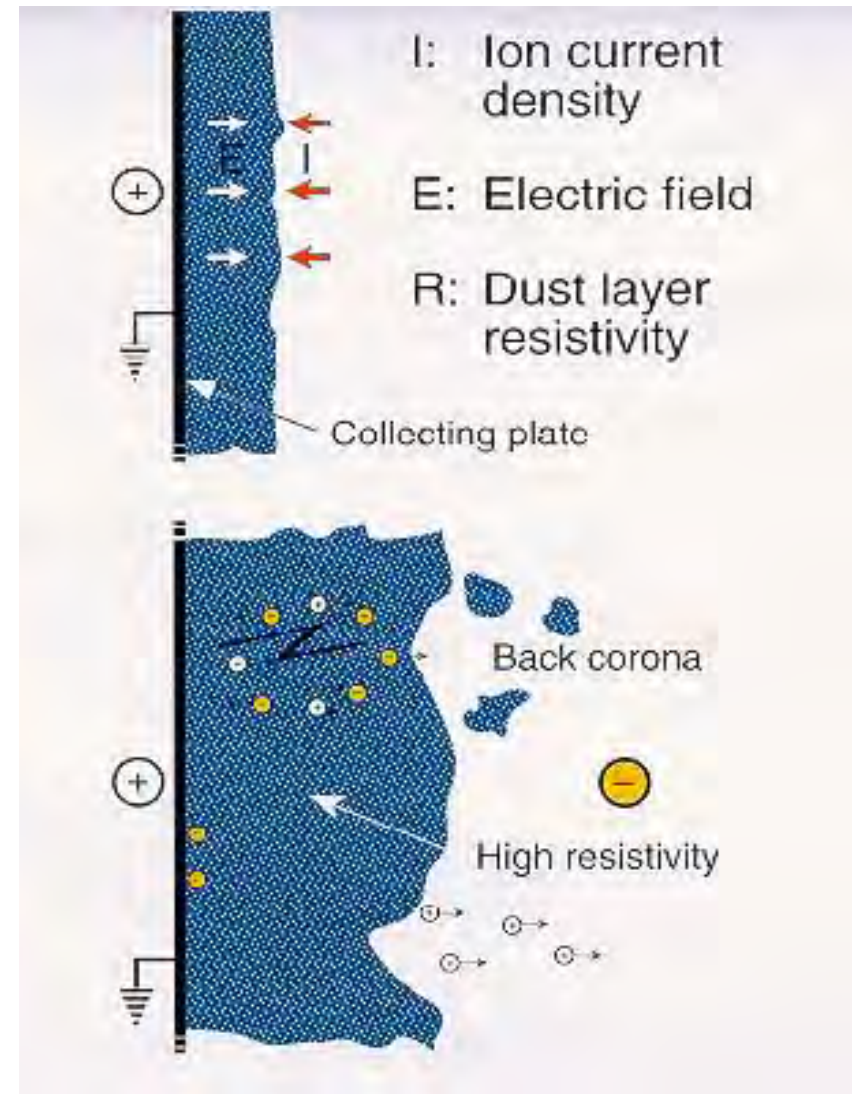
High resistivity dust, Back-Corona

$$E = j \rho$$

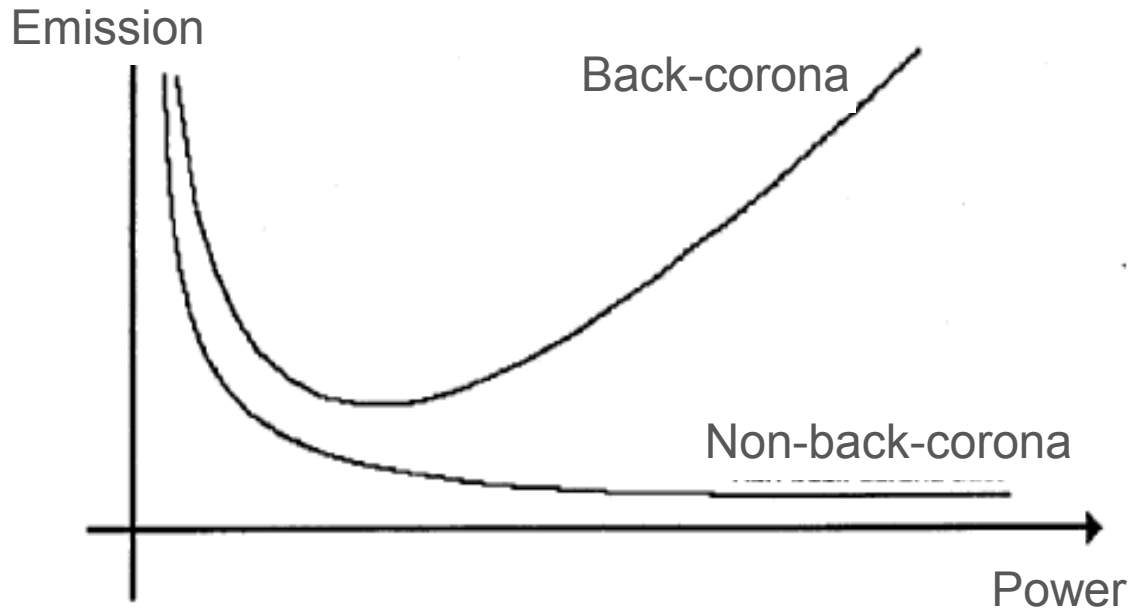
E Field strength, [V/m]

j Current density, [A/m²]

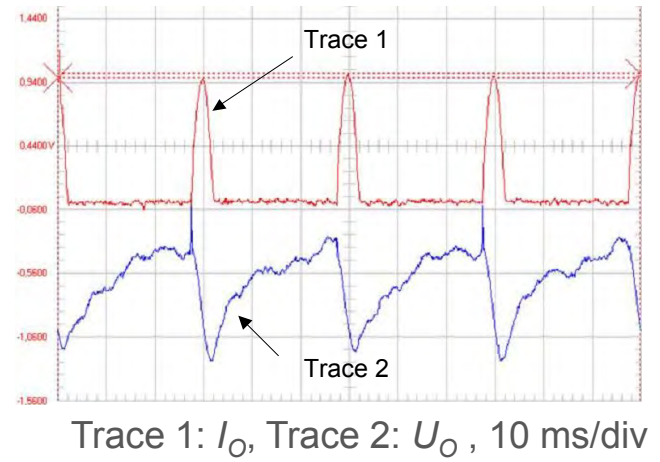
ρ Dust layer resistivity, [Ωm]



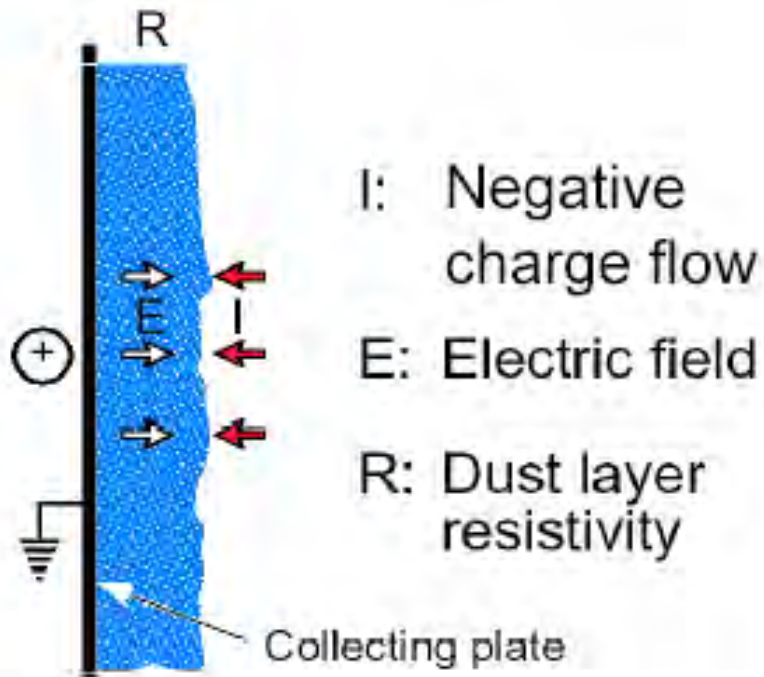
Dust emission vs. power consumption



Intermittent Energization, IE



Low resistivity dust, re-entrainment



Tear off

Gas flow (drag)
Gravity

Holding

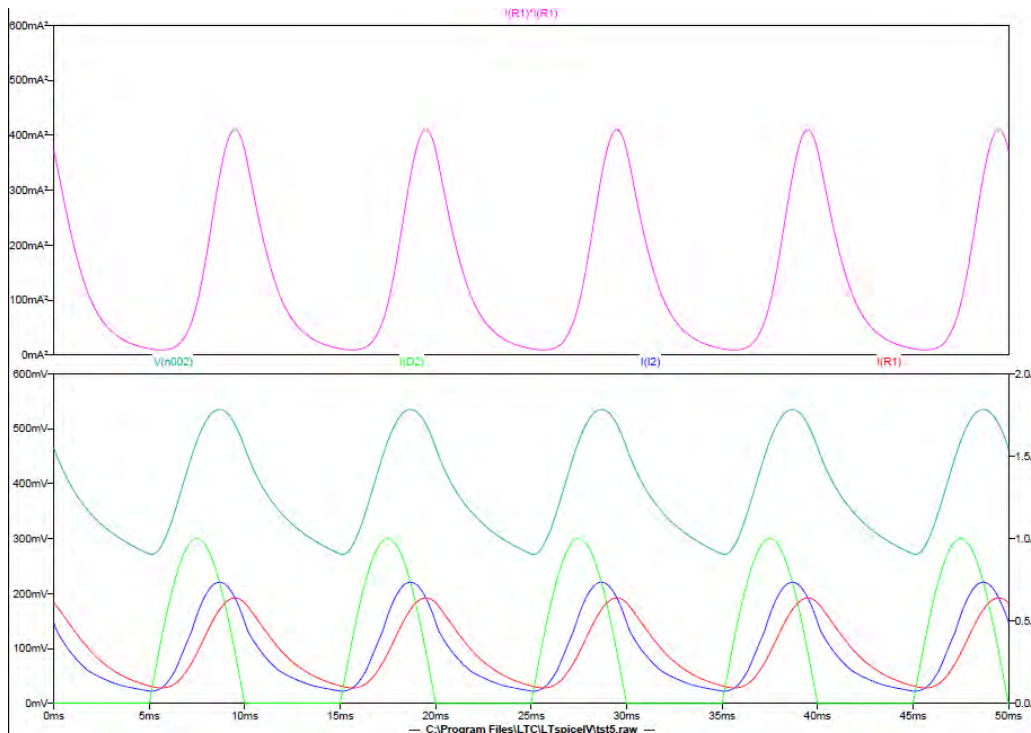
Electrostatic forces
Chemical (cohesion)

Re-entrainment related to low resistivity depends on the relation between dust layer electrostatics and gas flow close to the collecting electrode.



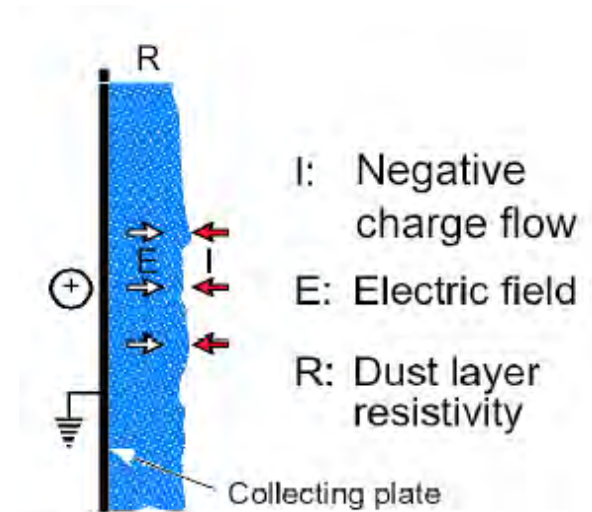
Conventional TR, 1:1 operation

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

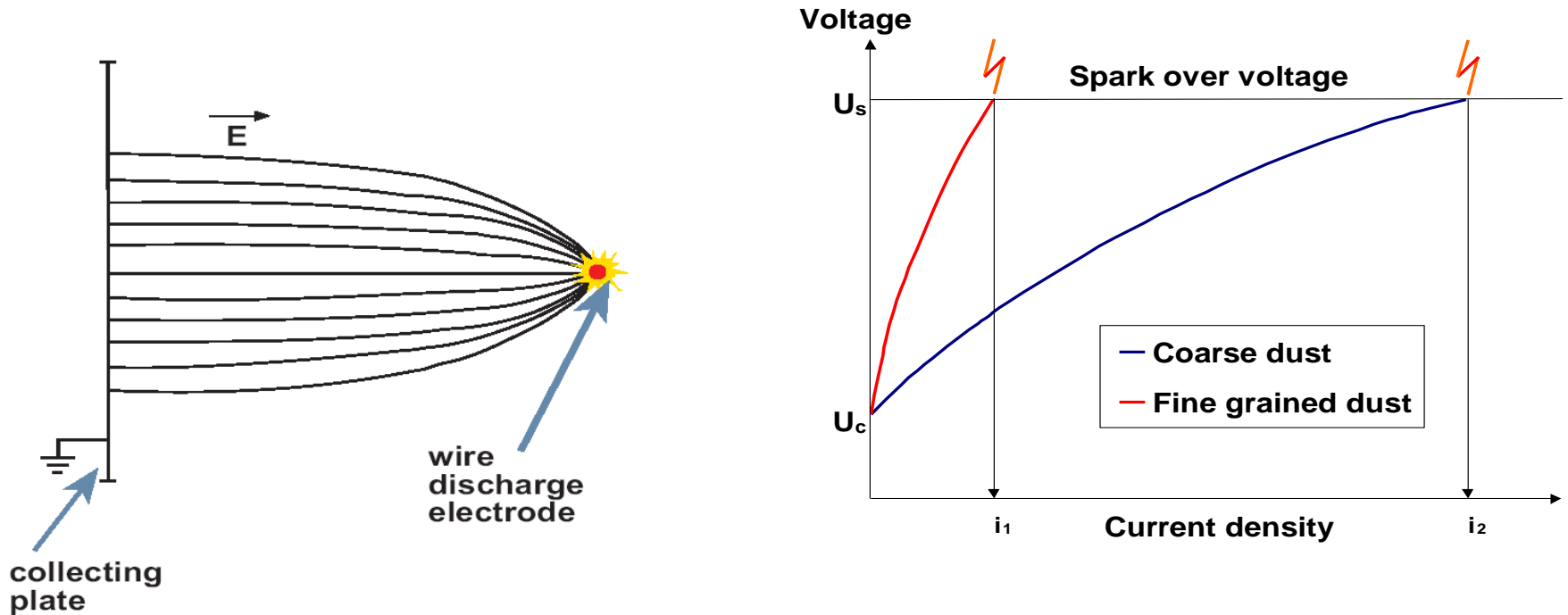


$$T = \rho \varepsilon$$

T Time constant
 ε Dielectric constant
 ρ Dust layer resistivity



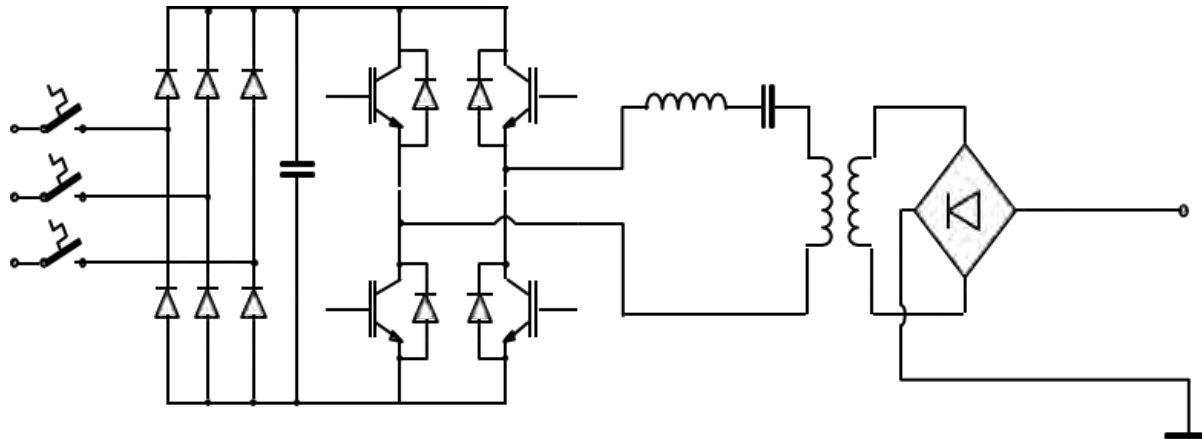
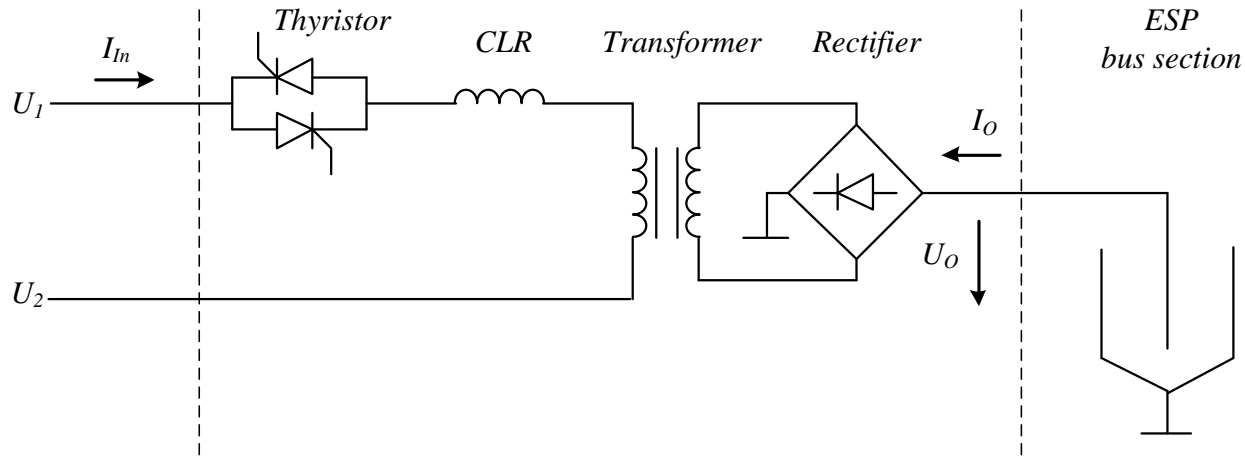
Corona quenching, space charge effect



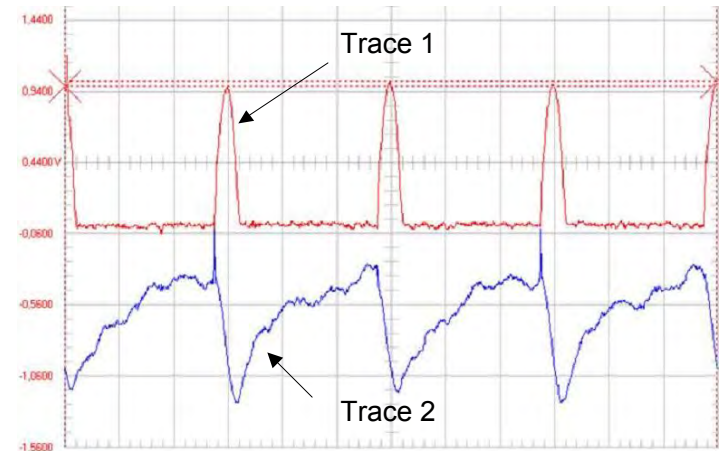
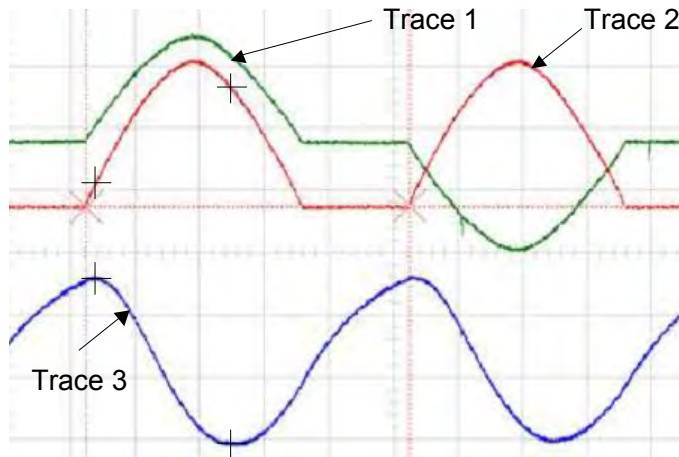
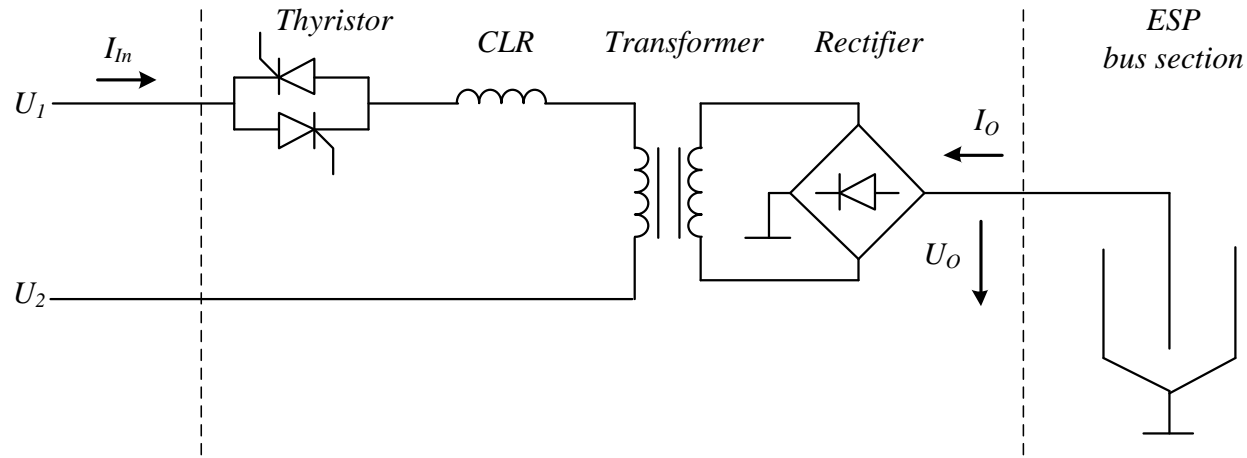
Fine grained dust increases the Space Charge Effect, i.e. Corona Quenching, reducing collecting efficiency.



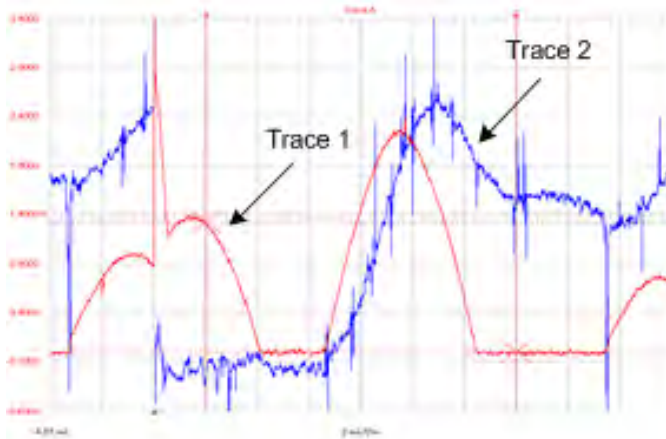
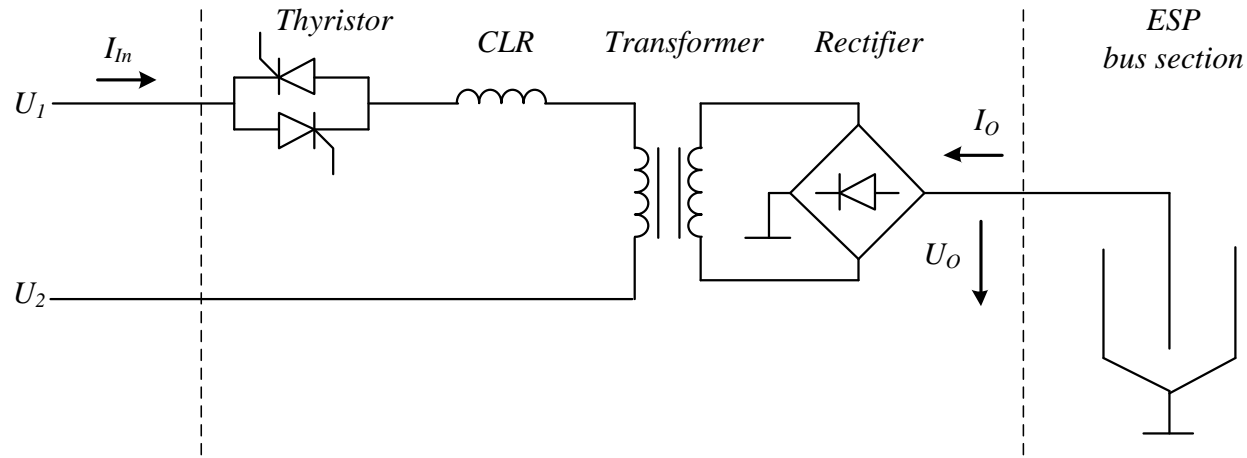
Thyristor vs Inverter based power supply supplies



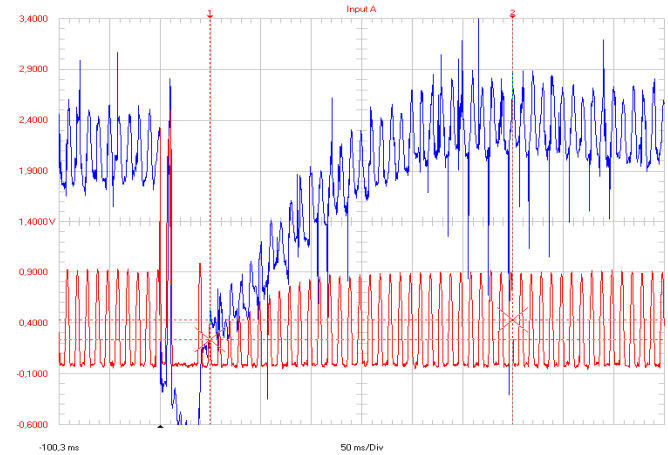
Thyristor and TR based system, single phase



Thyristor and TR based system, single phase



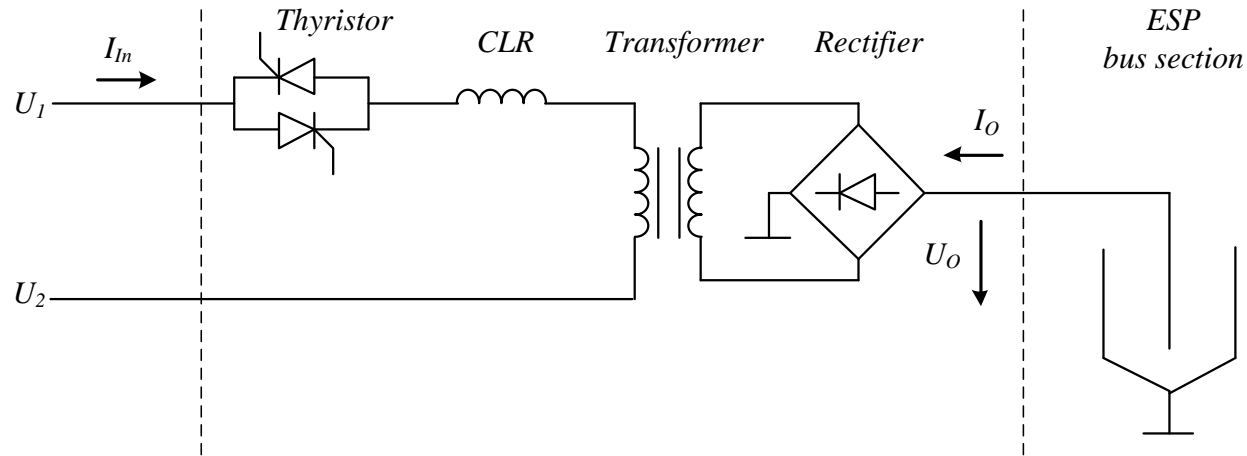
Spark quenching.
Trace 1: I_o , Trace 2: U_o , 2 ms/div



Spark recovery
Trace 1: I_o , Trace 2: U_o , 50 ms/div



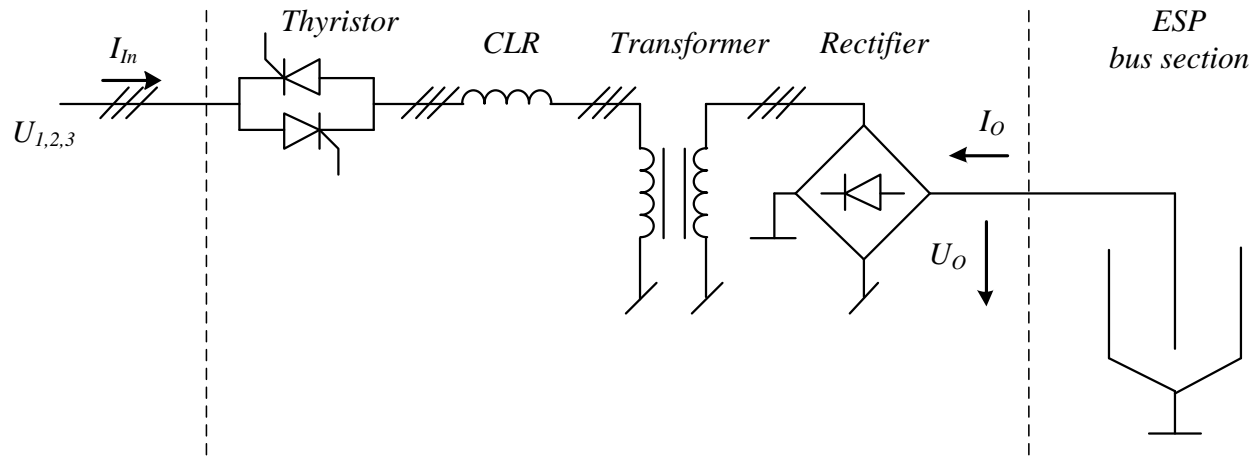
Thyristor and TR based system, single phase



- Dominating installed base
- High voltage ripple, reduces corona current
- IE works well, proven on high res. power.
- Slow control, 50/60 Hz
- Slow spark quenching
- Non-balanced load
- High reactive power consumption
- Low energy efficiency



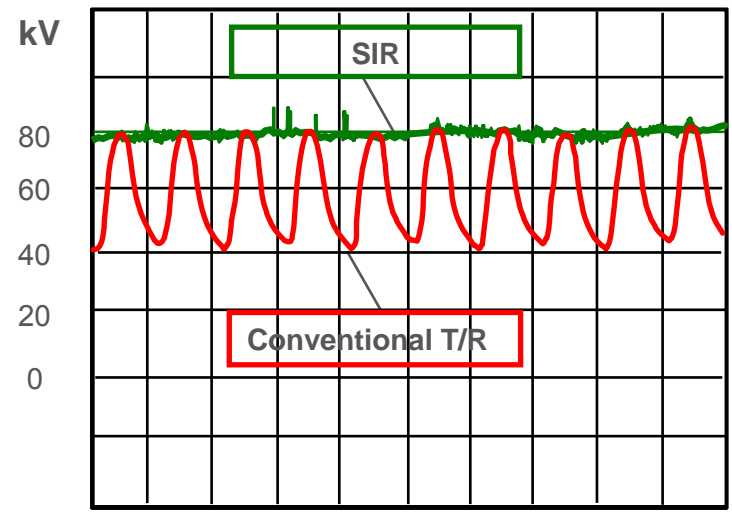
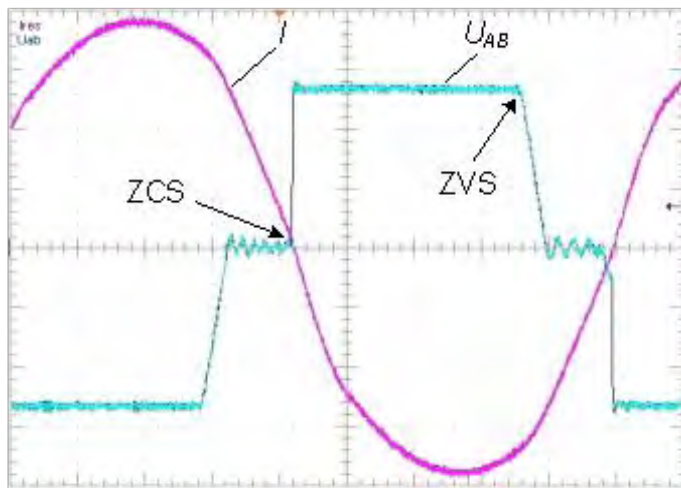
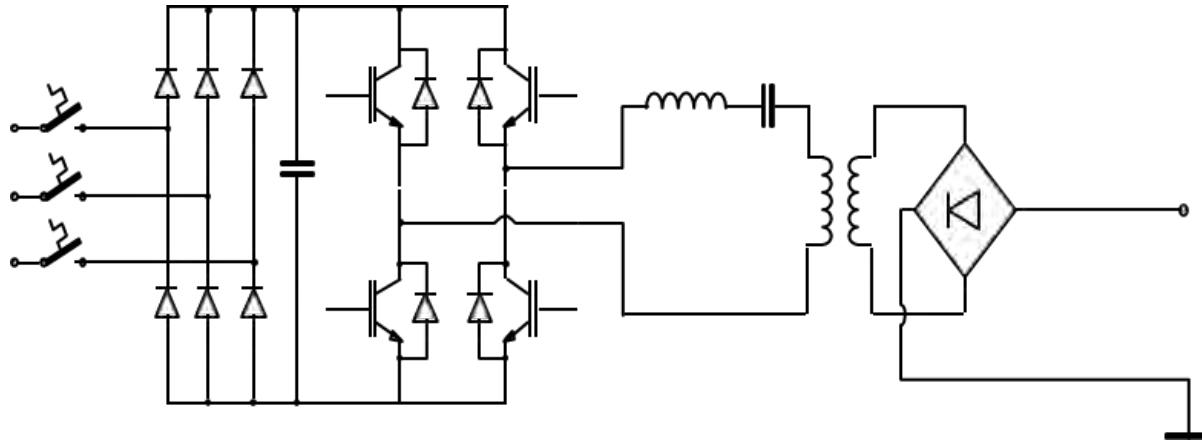
Thyristor and TR based system, three phase



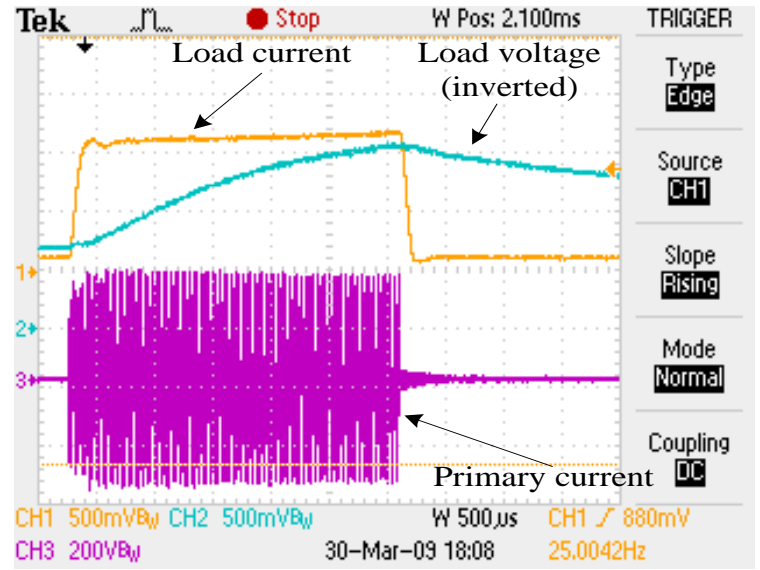
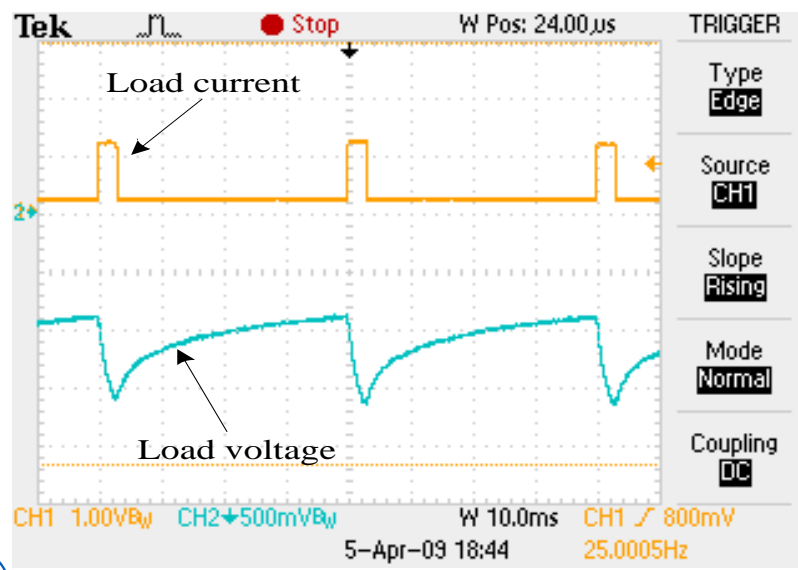
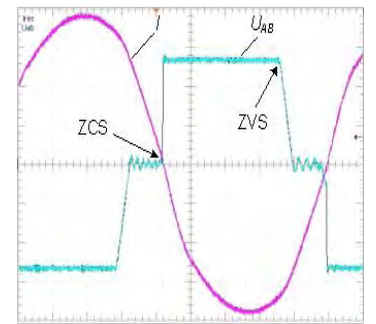
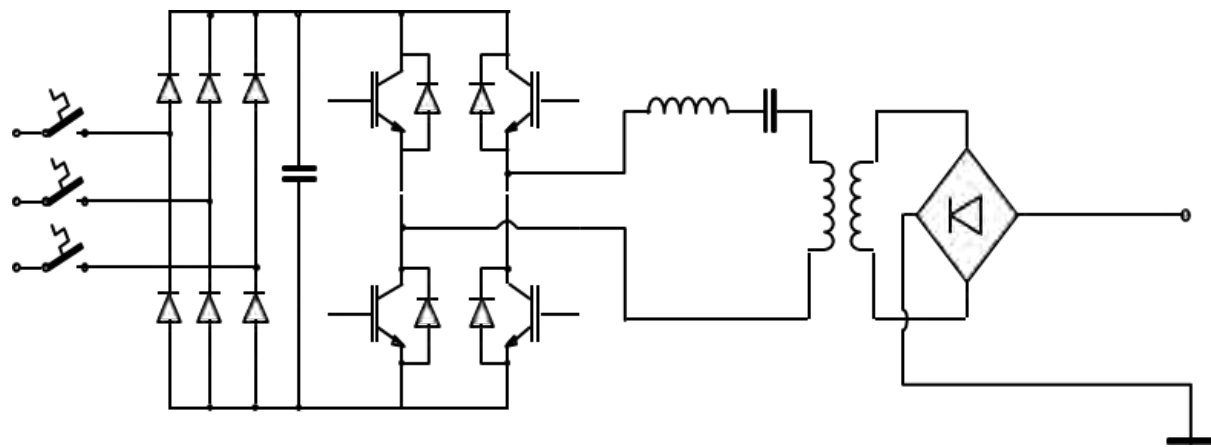
- Low voltage ripple, (vs single phase, U_n)
- IE complex, no ref
- Slow control, 50/60 Hz
- Slow spark quenching
- Balanced load
- Reduced reactive power consumption (vs single phase)
- Medium energy efficiency



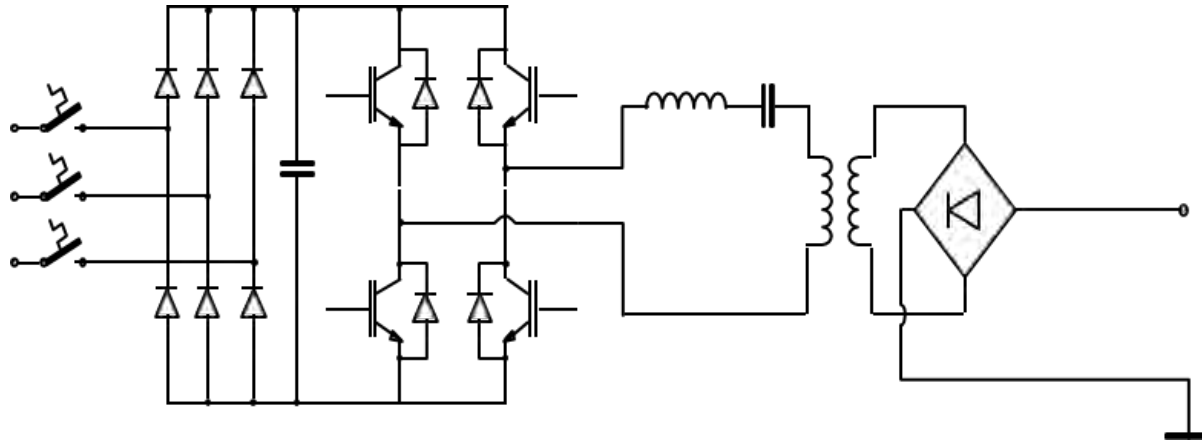
High frequency power supply



High frequency power supply, IE



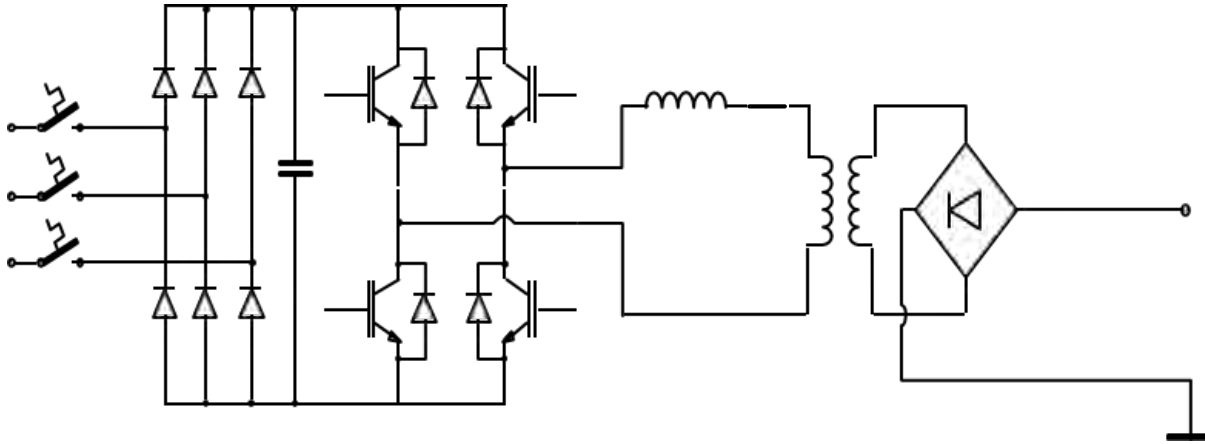
High frequency power supply



- Lowest voltage ripple, high corona current (many ref)
- IE works well, several ref.
- Fast control, 25 kHz
- Fast spark quenching
- Balanced load
- Low reactive power consumption
- High energy efficiency
- Integrated design



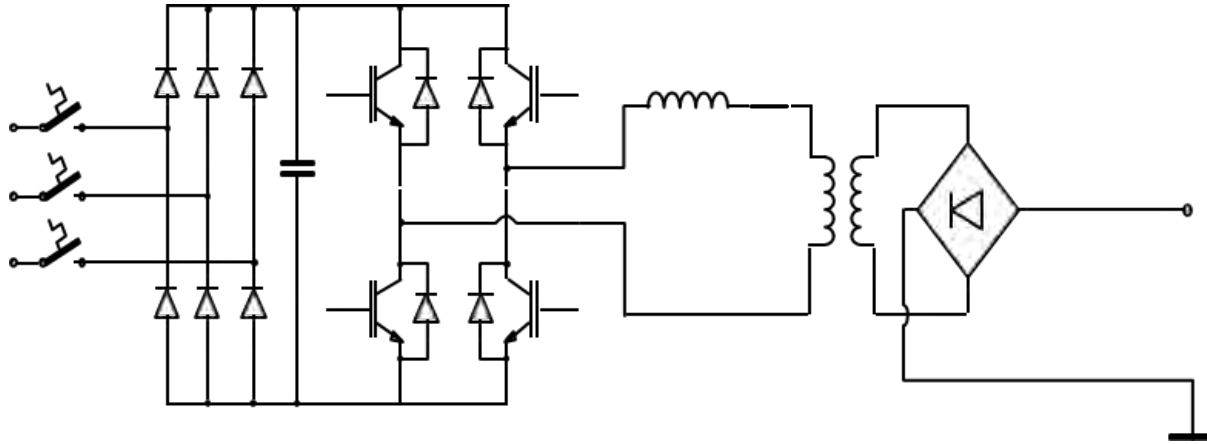
Mid frequency power supply



- Similar operation as HFPS but lower frequencies, hard switching IGBTs
- Power conversion frequency, 50 Hz – 1 kHz
- Improved spark quenching (vs Single phase)
- Direct control or modulation of current
- IE possible by modulation
- Reuse of TRs in upgrades?



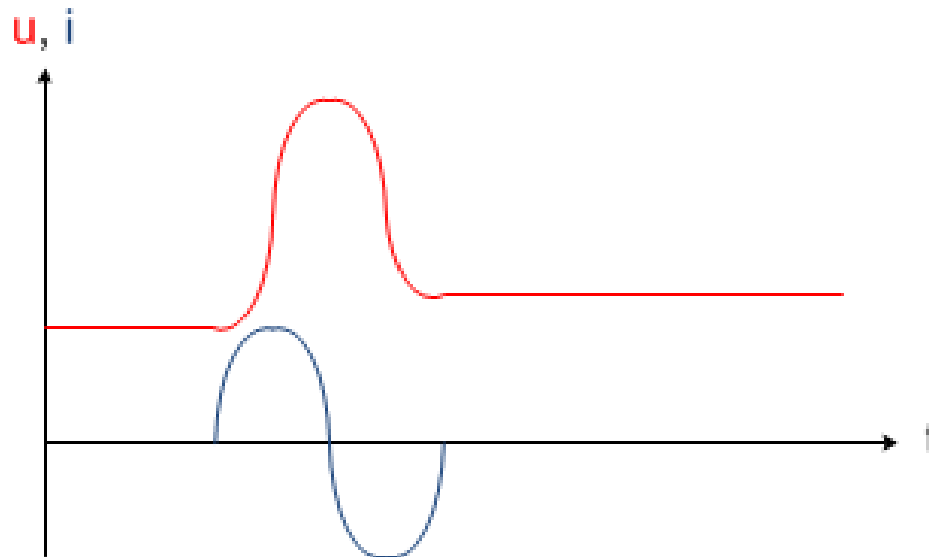
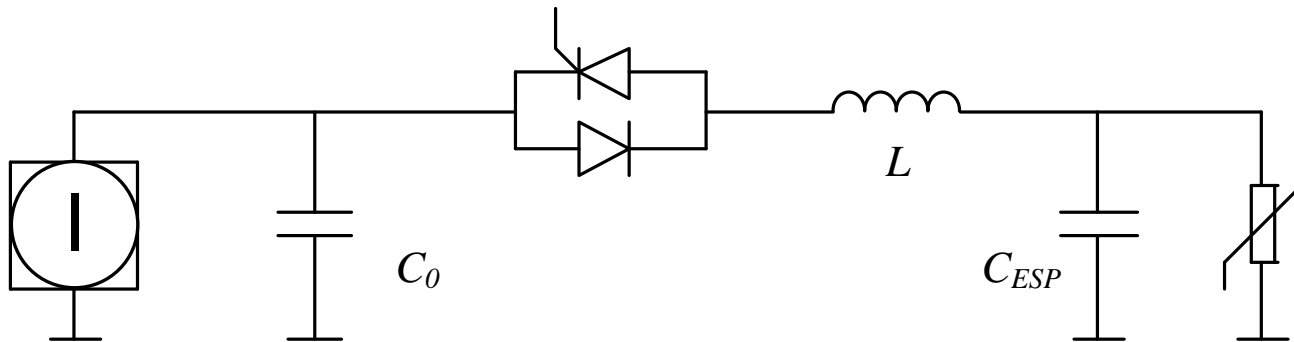
Mid frequency power supply



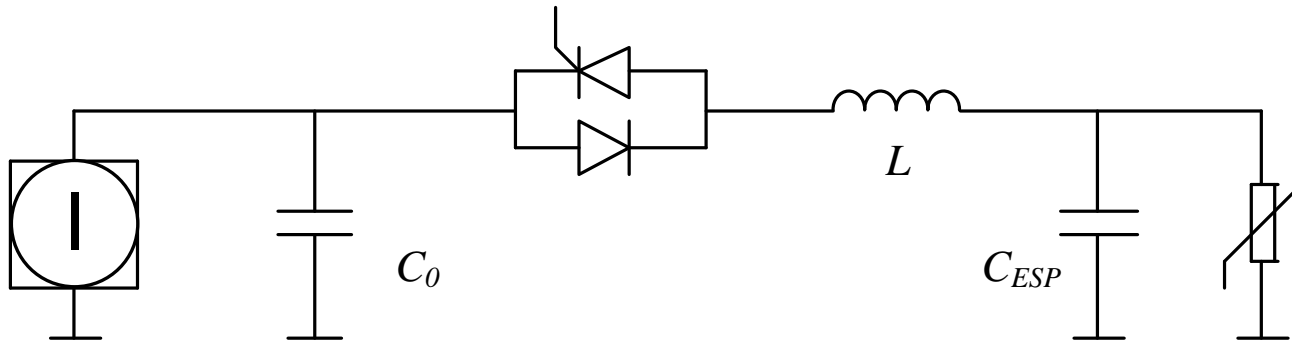
- Low voltage ripple
- IE possible, no ref
- Medium control response, 50 Hz – 1 kHz
- Medium spark quenching
- Balanced load
- Low reactive power consumption
- Medium energy efficiency?



Pulsed power supply, high voltage switching



Pulsed power supply



- Targets very high resistivity appl, power and ind
- Weak on low resistivity, low average power
- Low energy efficiency
- Grid interaction depends on charging power supply
- High weight and volume
- High cost



Our mission



