

REINHOLD ENVIRONMENTAL Ltd.



2010 APC Round Table & Expo Presentation

July 18-20, 2010, in Concord, NC / Hosted by Duke Energy

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APC Roundtable

Mid Frequency Power Supplies for ESPs

Roland Metz, Siemens Industry, Inc.
Dr. Michael Steingraeber, Siemens AG

SMPS – Switch Mode Power Supply Medium Switching Frequency

SIEMENS

The requirements for the development of the first 3-phase AC SMPS with power semiconductors (transistors) in 1988 were:

- Generation of a flat DC voltage up to 110kV
 - Rated power up to 200kW
 - Fast spark detection/reaction to avoid over current at short circuit conditions (spark, flash-over) and for fast ESP recovery
 - High availability for harsh ambient conditions at the installation site (temperature, gas conditions, dust ..)
- This led to the development of the first SMPS inverter system based on transistors with 1kHz switching frequency rated for 200kW and with standard separation of control cabinet and T/R set.



SMPS – Switch Mode Power Supply Medium Switching Frequency



Today, after more than 20 years experience with SMPS, the technical requirements are:

- SMPS rated power up to 200kW and higher
- 3-phase input voltage 380V up to 690V
- ESP voltages up to 150kV due to the tendency for increased ESP gas passage
- High signal sampling rate for fast scan and reaction to sparks/arcs
- Integrated optimization functions to maximize ESP efficiency at all operating conditions
- Easy accessibility of all components and high availability even at poor ambient conditions
- Reuse of existing 60Hz T/R sets as low cost upgrade solution
- Quick determination of the advantage with SMPS IGBT based power supply at existing ESP installations

SMPS – Switch Mode Power Supply IGBT Control with Medium Switching Frequency



Available up to
275kW

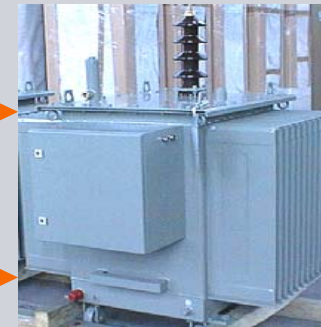
3 phase main



1 phase, 500Hz

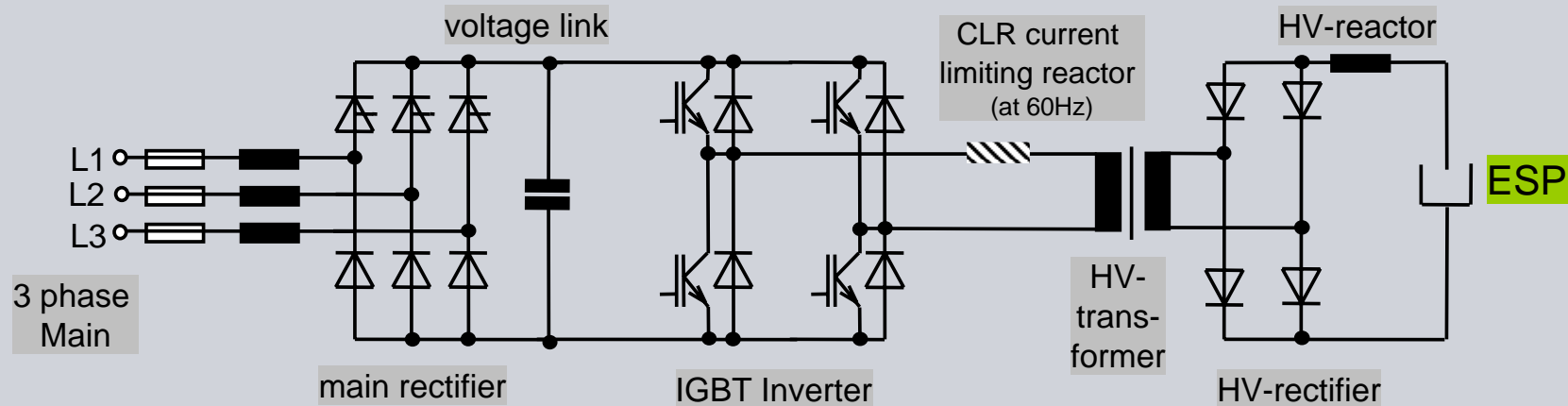
or

1 phase, 60Hz



New, special
500Hz T/R-set

or
Reuse of existing
60Hz T/R-set



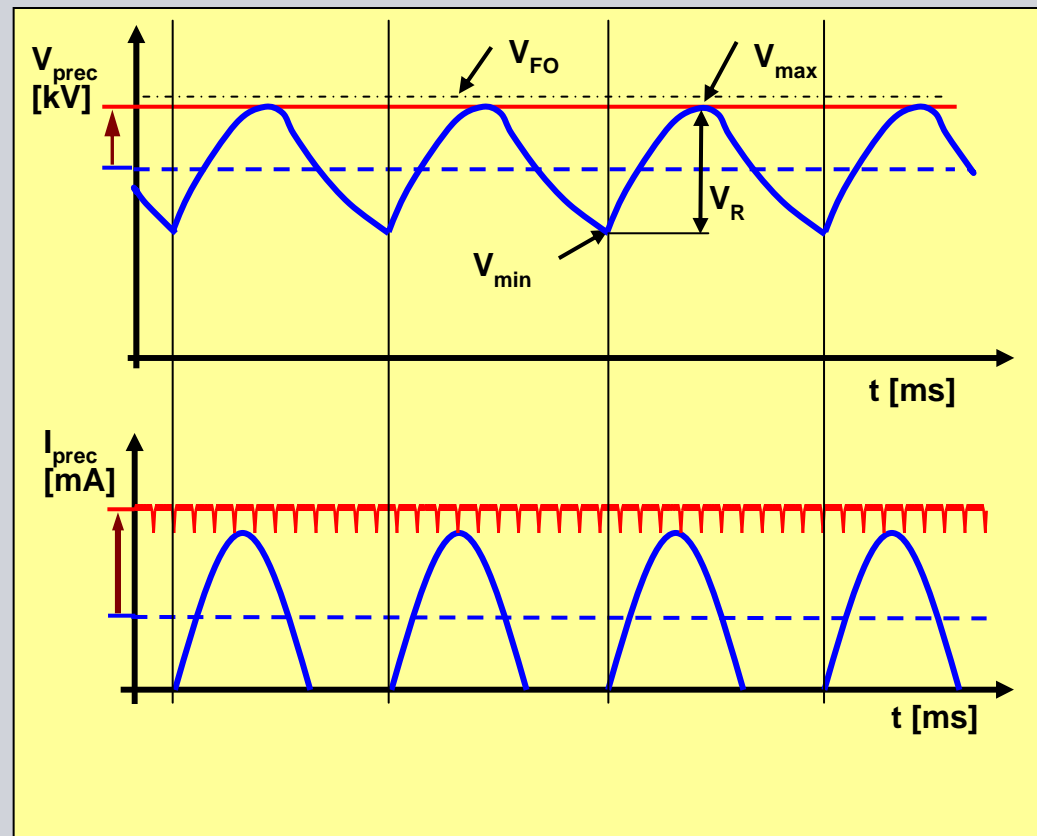
Comparison SCR (60Hz) – SMPS (500 Hz)

Conventional thyristor control (SCR - silicon controlled rectifier):

- Max. ESP voltage and current limited by ESP discharges

SMPS - IGBT Inverter

- Ripple extremely small due to short switching times
- Increased average voltage and current
- Substantial increase of corona power

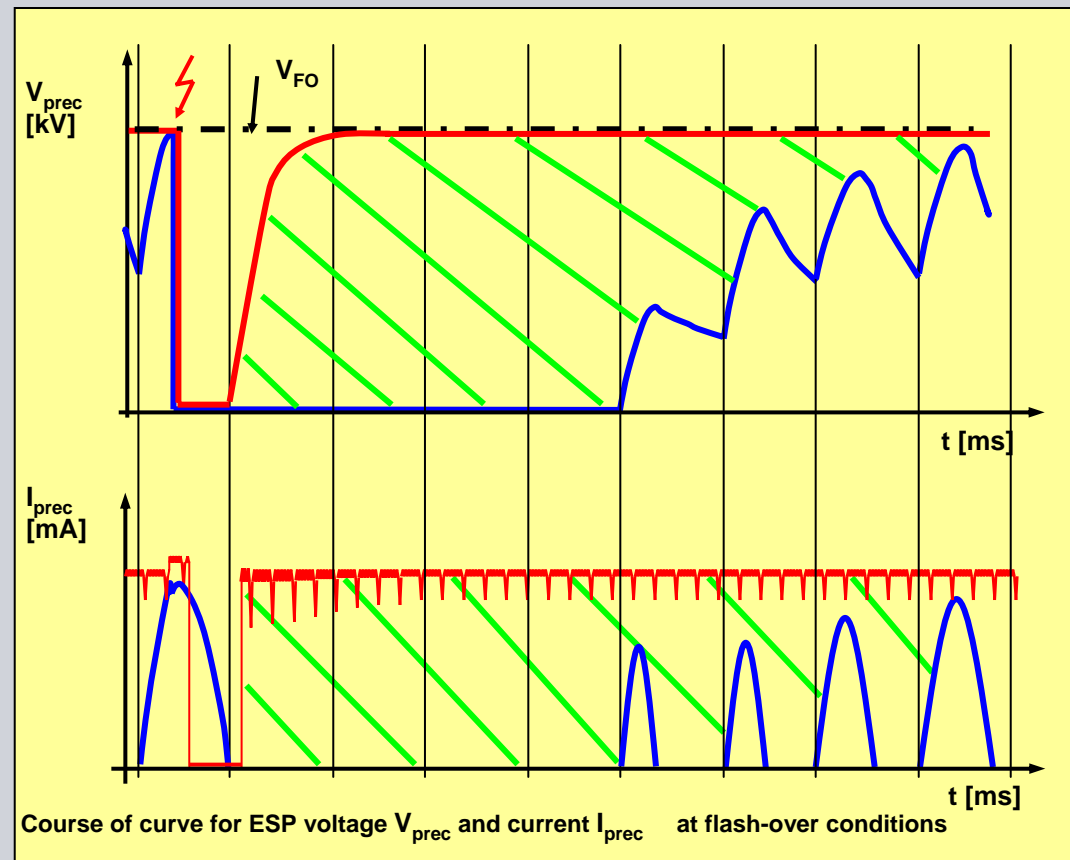


➤ **Increased ESP efficiency**

Comparison of thyristor (blue) and IGBT power supplies (red) voltage/current curves

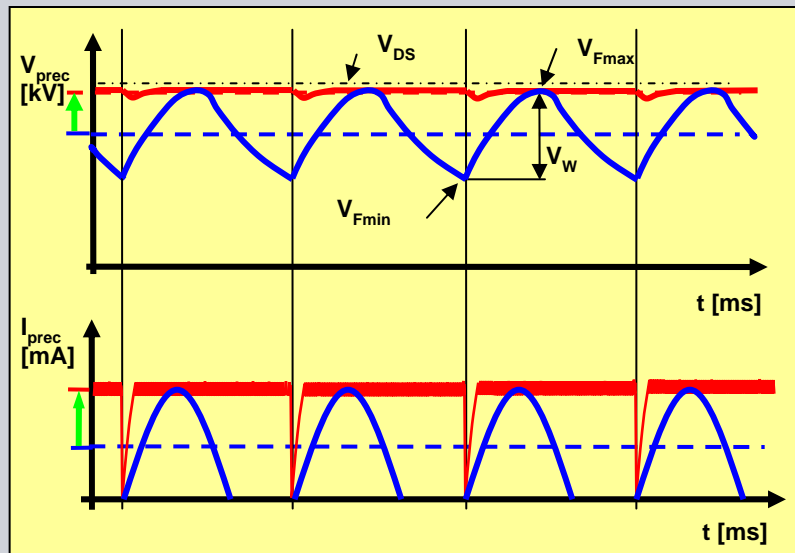
Comparison SCR (60Hz) – SMPS (500 Hz)

- IGBTs can be switched independently
 - Almost no over current at flash-over
 - Short deionization time
 - Fast recovery of ESP voltage/current
- **Increased corona power during spark processing**
- **Insensitive ESP operation even during process disturbances**



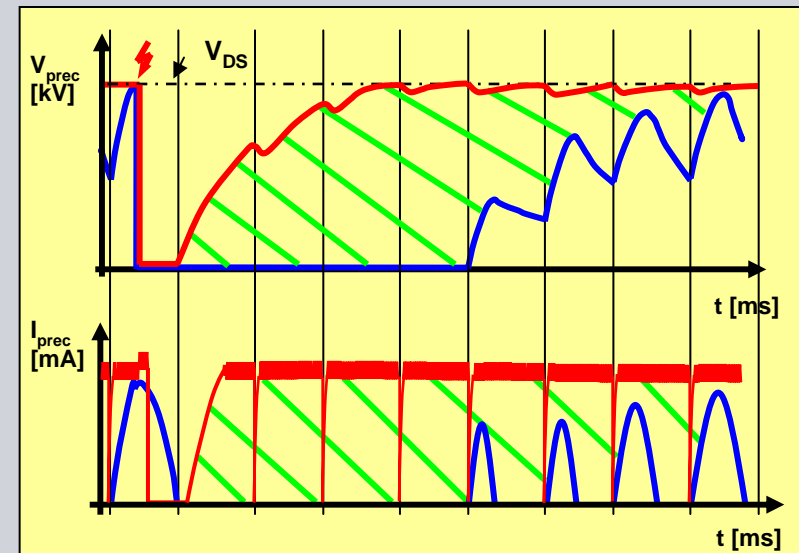
Comparison of Thyristor (blue) and IGBT power supplies (red) voltage/current curves during flash-over processing

Comparison SCR (60Hz) – SMPS (60 Hz)



Curves for ESP voltage VF and current IF of Thyristor (blue) and IGBT (red) power supplies

- Reduced ESP voltage ripple
- Increased corona power
- 3 phase connection
- Power factor close to 1
- Reduced modernization costs with reuse of existing T/R-sets



Curves for ESP voltage VF and current IF at flash-over conditions

- Reduced short circuit current
- Decreased deionization time / fast recovery of ESP voltage/current
- Increased performance during flash-over processing

ESP Operating Characteristic

Situation A:

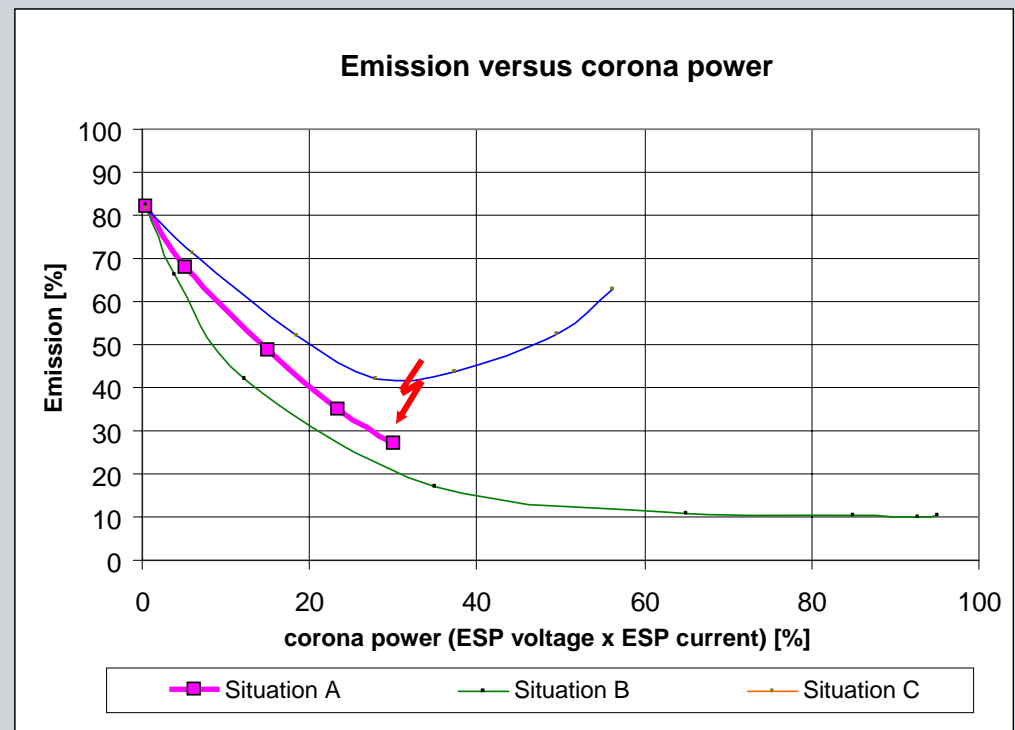
Typical for all inlet fields and small ESPs. Corona power limited due to sparks. Potential for **SMPS**

Situation B:

Typical for large ESPs and/or low production rate. Potential for **energy savings**

Situation C:

Back corona conditions where corona power must be controlled with **pulse mode**

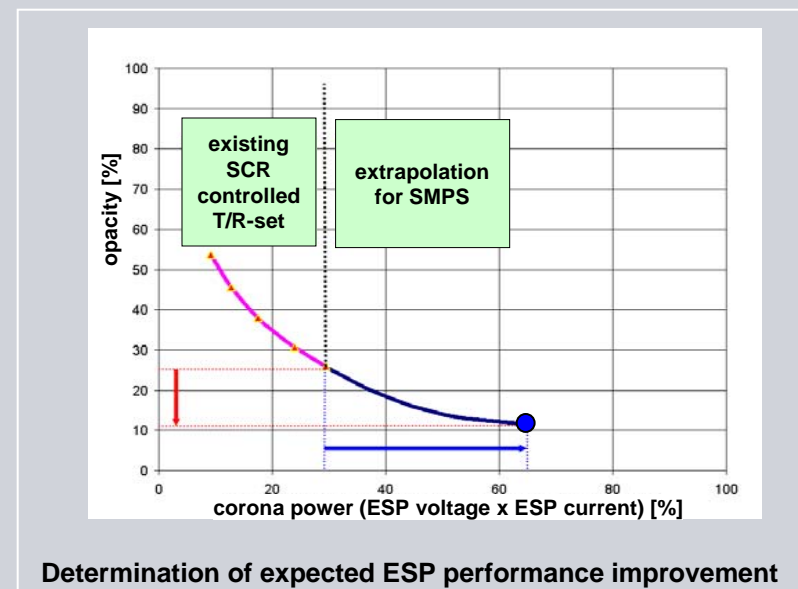
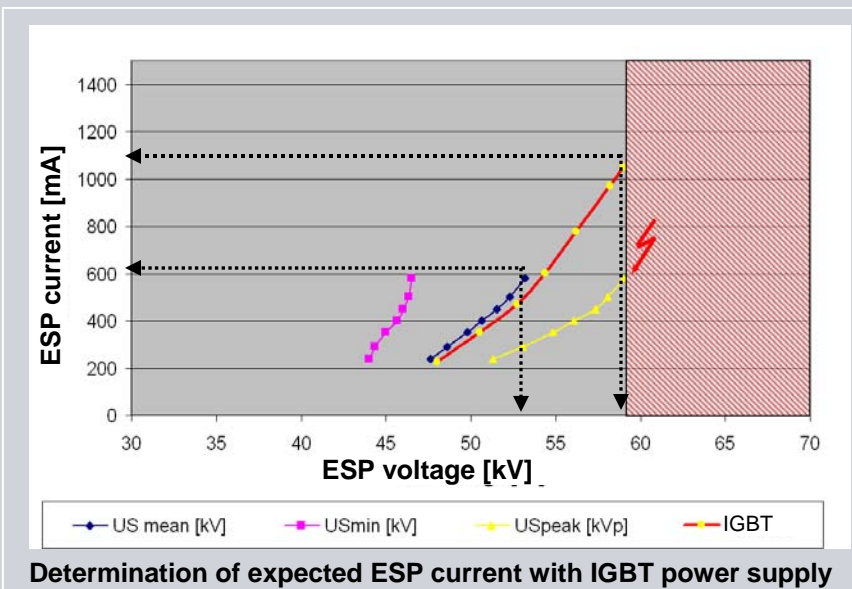


SMPS – Switch Mode Power Supply

Determine the Potential prior to Investments

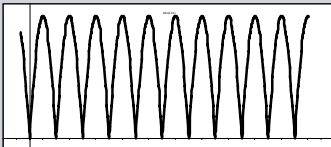
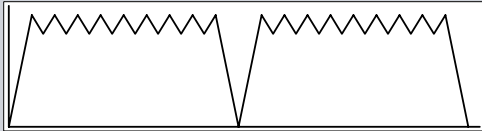
- Simple pre-test with the existing equipment:
 - Opacity signal recording
 - Scanning of static I/V curve
 - Determination of max. ESP voltage/current with SMPS
 - Graph opacity = f (corona power)
 - Determination of opacity decrease

- Trial installation for performance check at real operating conditions



Comparison SMPS types

High Frequency – Medium Frequency (1)

Properties:	Resonant (HF)	Hard switching (MF)
Type:	High Frequency	Medium Frequency
Current waveform:		
Input Phases:	3	3
Power Factor:	~ 1	~ 1
Operating frequency:	high (e.g. 20kHz-80kHz)	moderate (500 Hz / 10 kHz)
T/R-set operating frequency:	20 kHz – 80 kHz special TR required	- 500 Hz (optimum) - 60Hz using standard T/R sets
Switching losses:	Low energy losses per switching event, but higher frequency	Higher energy losses per switching event, but lower frequency
Power losses:	High (fast IGBT needed, higher V_{CE0})	Low (high current type IGBT, lower V_{CE0})

Comparison SMPS types

High Frequency – Medium Frequency (2)

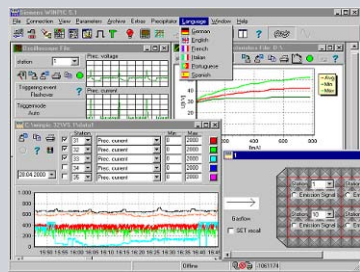


Properties:	Resonant (HF)	Hard switching (MF)
Power supply upgrade:	Always replace inverter and T/R-set	Reuse of existing T/R-sets possible
T/R-Set type:	Low losses (Ferrite)	500 Hz or standard 60Hz
T/R-Set size:	Small for the same power rating compared to standard T/R set but limited as high voltage requires insulation distance.	Little smaller compared to standard T/R set
Distance Inverter – T/R-Set:	Not possible due to high frequency	- 500 Hz T/R-set: <u>120m (~400 ft)</u> - 60Hz T/R-set: <u>any</u>
T/R-Set core	small, Ferrite	Iron plates
Maximum power:	120 KW	<u>300 kW and higher</u>
Maximum voltage:	70 – 100 kV (DC)	<u>150kV</u> (DC) and higher possible
Maximum current:	1.7 A (with 70kV max.)	3.3 A (with 90kV max.)
Spark reaction:	fast	fast
Spark current increase:	no	no

SMPS – Switch Mode Power Supply IGBT Controller components

IGBT Control cabinet

T/R-set



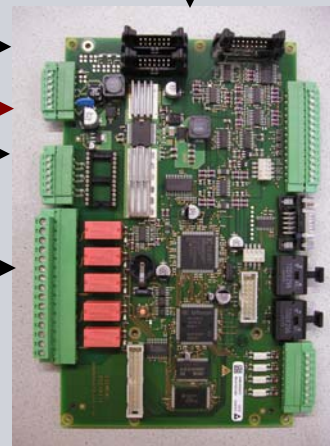
Operating and diagnostic Software



Operating panel Touch screen

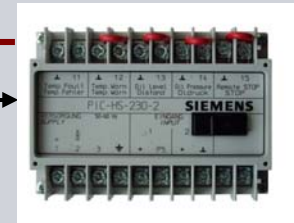
micro-controller PIC 167-1

4 digital inputs
2 analog in-/outputs
5 Relay-outputs



signals [mA], [kV], [T/R-set protection] via optical fiber cable

HV-acquisition unit PIC HS 115-2

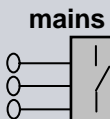
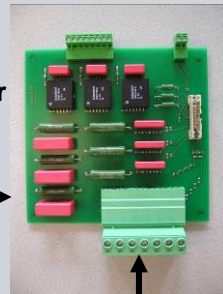


power supply integrated at fiber optical cable



SITOP power supply

GAX 167 main rectifier control



mains

Breaker / Fuses

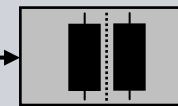
commutating reactor

main rectifier

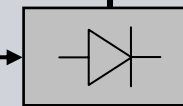
Voltage link

IGBT-inverter

IGBT Assembly



HV-transformer

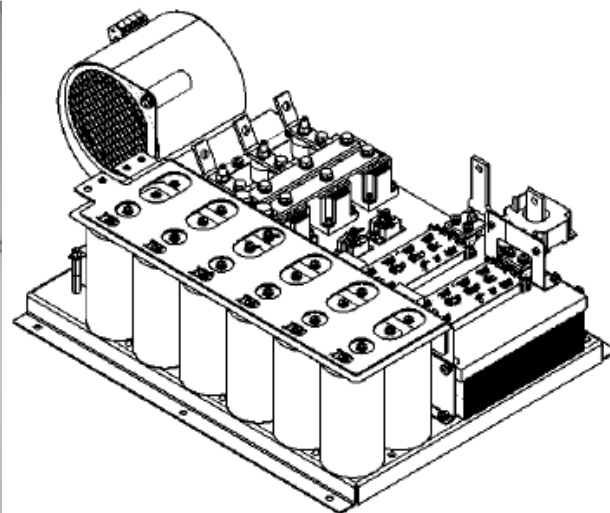
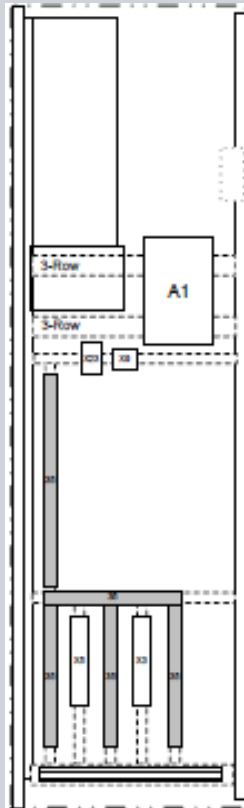


HV-rectifier

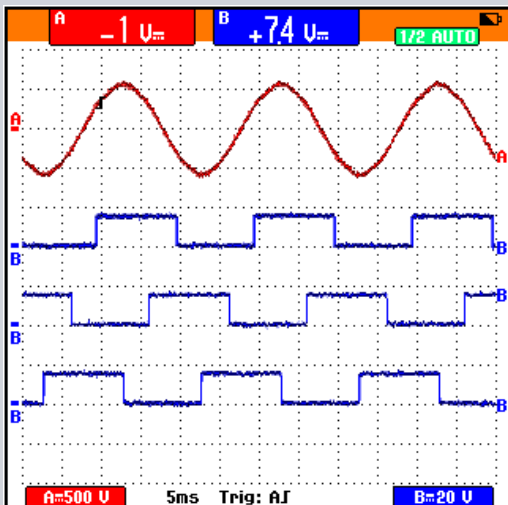
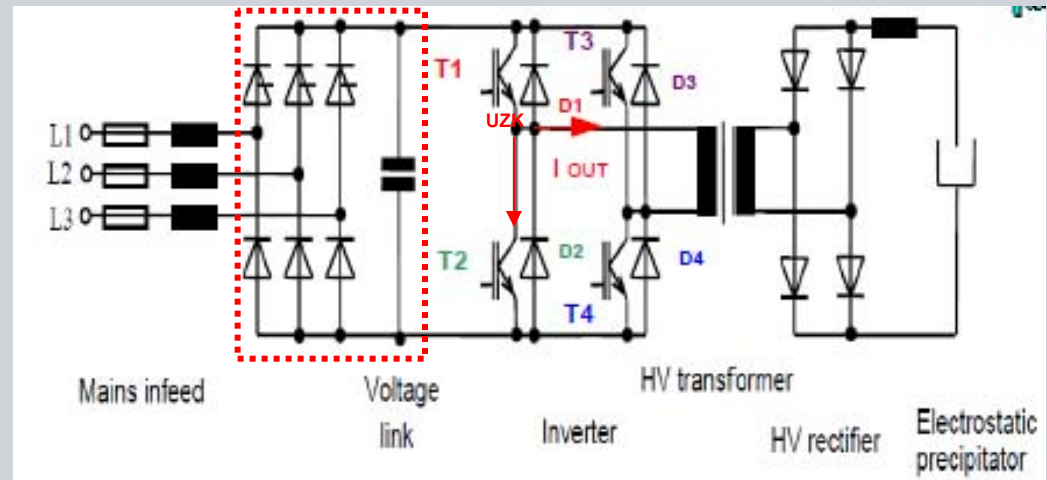
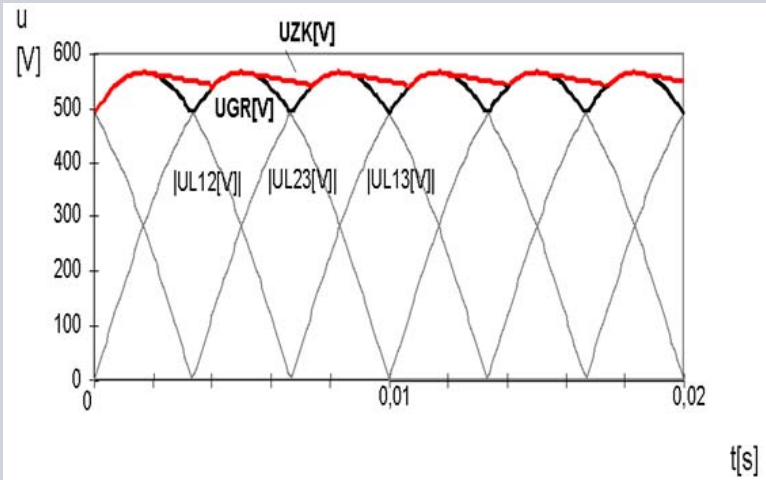
ESP

SMPS – Switch Mode Power Supply Power Electronics

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SMPS – Switch Mode Power Supply Typical Operating Wave Forms (500Hz)

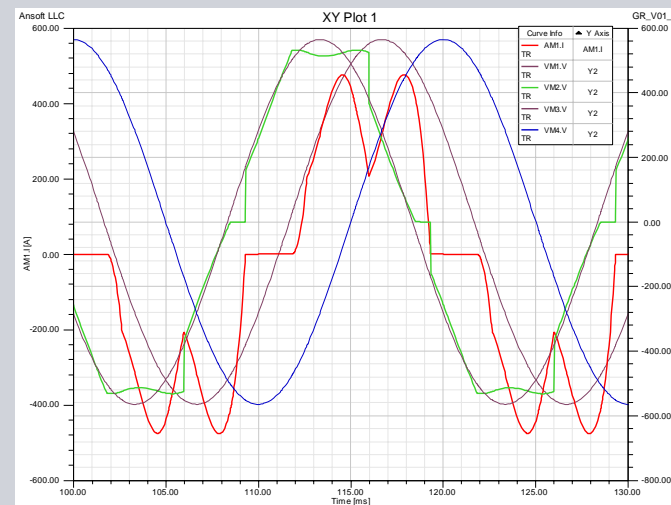


Phase L1-L2

Gate L1

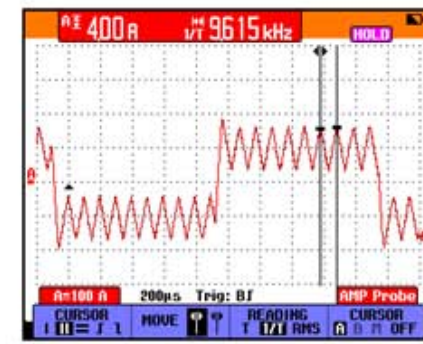
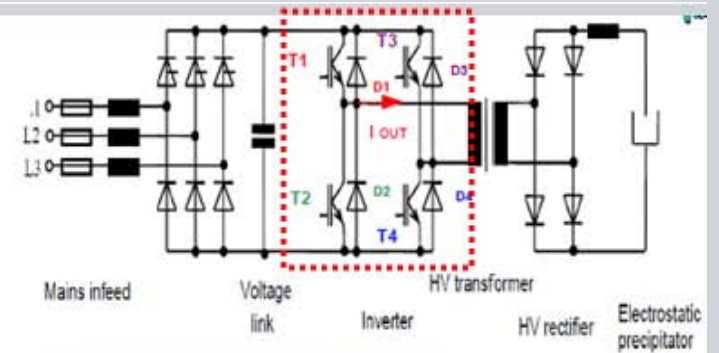
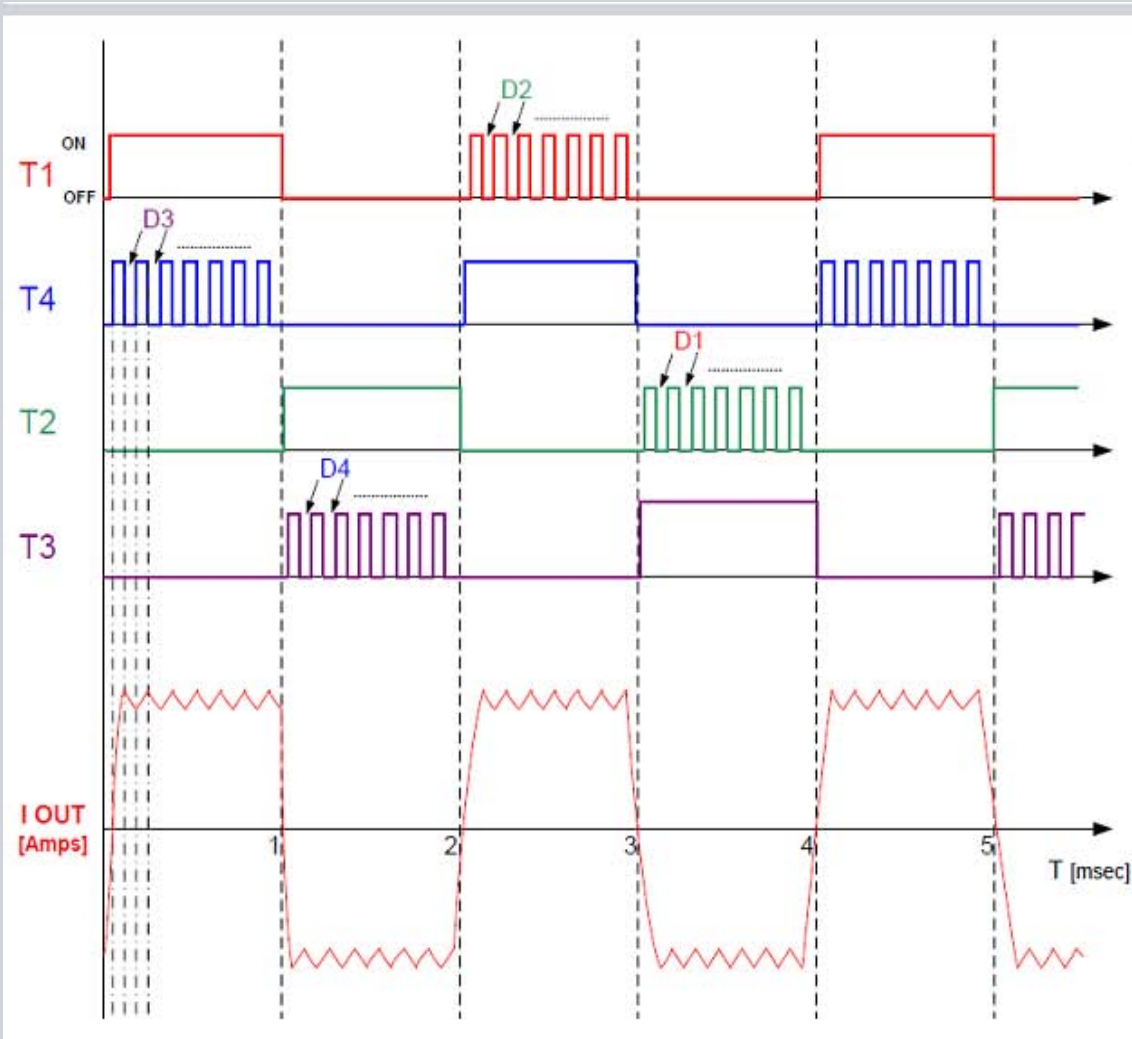
Gate L2

Gate L3

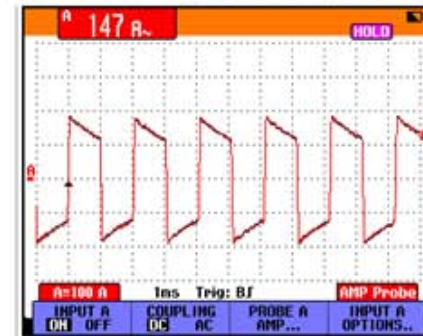


$I_1 = 365 \text{ A}$

SMPS – Switch Mode Power Supply Typical Operating Wave Forms (500Hz)



Primary current
T/R set with
field load

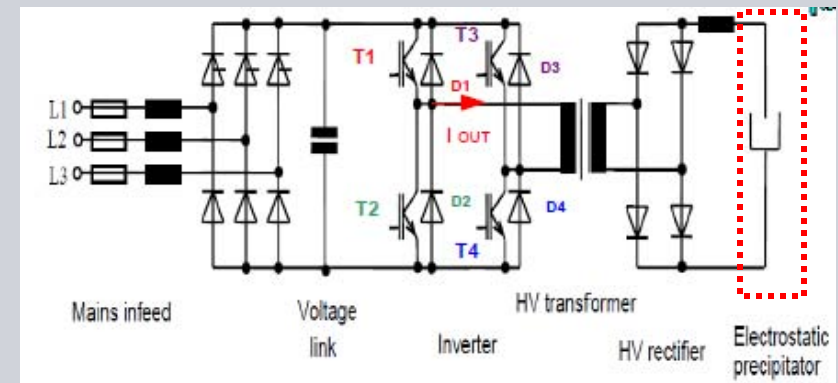
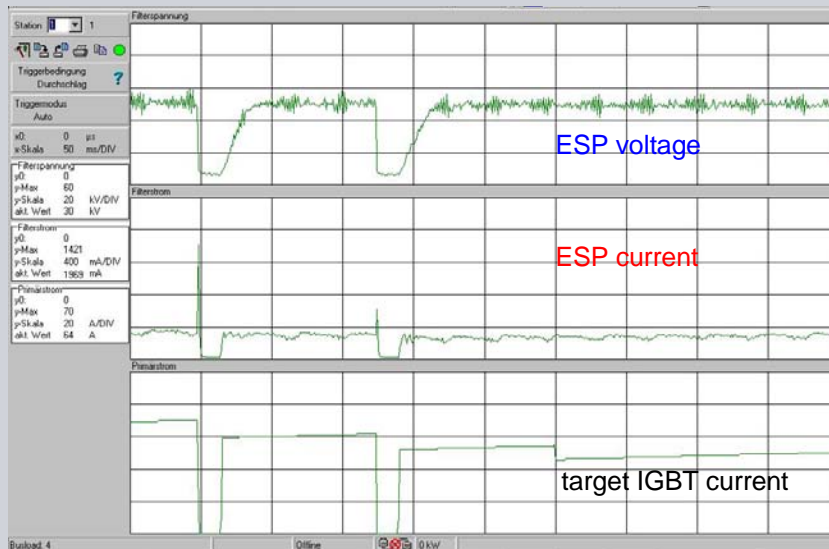


Primary current
T/R set with
secondary
short circuit

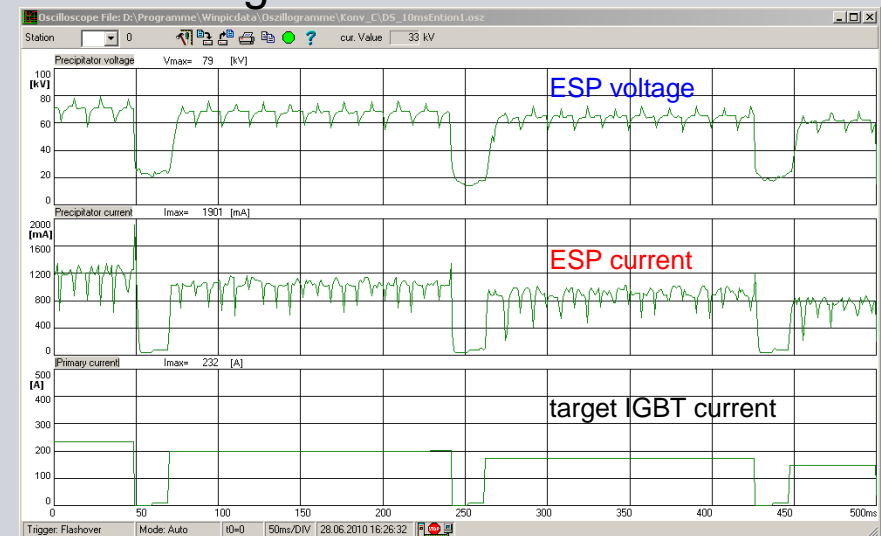
SMPS – Switch Mode Power Supply Typical Operating Wave Forms

SIEMENS

500Hz switching frequency



60Hz switching frequency and reuse of existing T/R set



SMPS – Switch Mode Power Supply T/R set Reliability and Maintenance



T/R sets do have a high reliability (proven technology) and are nearly maintenance-free except for the following standard occasional checks:

- oil level
- damage of paintwork
- dust deposits (cleaning of HV bushing)
- cable for condition and proper connection
- T/R set protection devices for proper functioning

With hermetically sealed T/R sets no insulating fluid check is required.

SMPS – Switch Mode Power Supply IGBT Control Cabinet Reliability and Maintenance



IGBT control cabinets do also show a high reliability (experience from 18 years of operation). The following maintenance work needs to be carried out:

- dust deposits should be removed from inside the unit at least once a year
- optional existing filter mats of the cabinet ventilation should be cleaned in intervals according to site conditions
- power cable should be checked for proper connection
- the cooling fan is suggested to be exchanged after approx. 70,000 operation hours
- the thyristor & IGBT modules and voltage link capacitors are suggested to be exchanged depending on the operating conditions after approx. 70,000 operating hours

Siemens ESP Power Supply History

- 1919: rotating mechanical rectifiers
- 1928: first selenium rectifier
- 1931: controlled mercury vapor tube as the first electro-mechanic ESP controller
- 1955: 2-phase AC transducer controlled by variable transformer
- 1968: 2-phase and 3-phase AC transducer with thyristor control
- 1969: 2-phase AC thyristor control with analog controller
- 1979: 1st μ sec pulsing system with oscillating circuit
- 1982: 1st generation microprocessor based thyristor controller
- 1988: 3-phase AC transistor controlled inverter 1kHz; 2nd generation thyristor controller
- 1992: 3-phase AC IGBT controlled inverter 500Hz
- 1993: 3rd generation thyristor controller
- 1997: 2-phase AC compact SCR thyristor power packs & controls
- 1999: 2nd generation μ sec pulsing system with Cavatron pseudospark vacuum switch
- 2004: 3rd generation μ sec pulsing system with HV IGBT switching stack
- 2006: 2nd generation 3-phase AC IGBT controlled inverter 500Hz with Skiip modules
- 2009: 4th generation thyristor controller
- 2010: 3rd generation 3-phase AC IGBT controlled inverter 500Hz and mobile test unit

SMPS – Switch Mode Power Supply Benefits Mid Frequency Power Supply

SIEMENS

- Increased collection efficiency resulting in lower stack opacity
- Higher power factor which provides energy savings payback especially on larger ESPs
- High performance and reliability
- Possibility to reuse existing T/R sets
- Control cubicle placed in electrical control rooms not in the middle of the dirt
- Solid T/R sets for installation at harsh ambient conditions
- Easy access to all components



SMPS – Switch Mode Power Supply

Why invest in modernizing?

SIEMENS



Clean gas dust content too high

- Changed operating conditions (fuel)
- Decreased emission (opacity) limit



Low reliability

- Obsolete and susceptible T/R-sets/controls
- No Service / Spare parts available etc.



High energy costs

- No energy minimization system installed

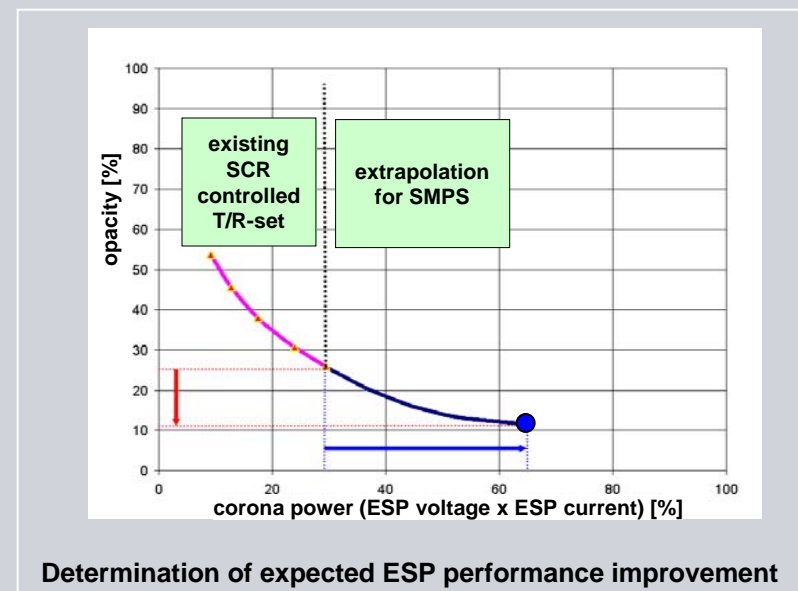
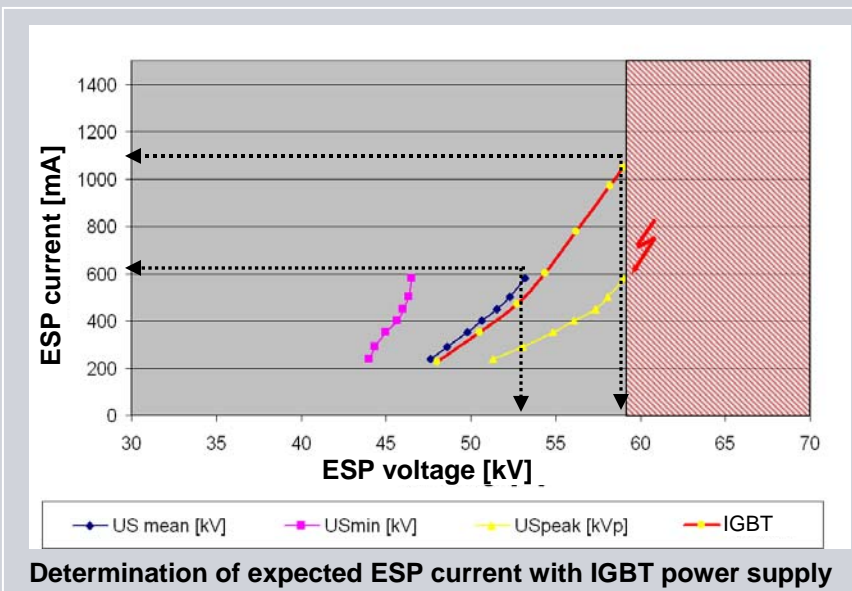


SMPS – Switch Mode Power Supply

Determine the Potential prior to Investments

- Simple pre-test with the existing equipment:
 - Opacity signal recording
 - Scanning of static I/V curve
 - Determination of max. ESP voltage/current with SMPS
 - Graph opacity = f (corona power)
 - Determination of opacity decrease

- Trial installation for performance check at real operating conditions



SMPS – Switch Mode Power Supply Trial Installation

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Solution 1:

Siemens offers trial installations with a **Mobile Test Unit**. The container comprises the required equipment for IGBT-technology with **operational and diagnostic software** inclusive all required cables from power supply to data link.



Solution 2:

Alternatively, the individual IGBT-components (IGBT cabinet and TR-Set) and the **operational software** PC-coupling can be used.

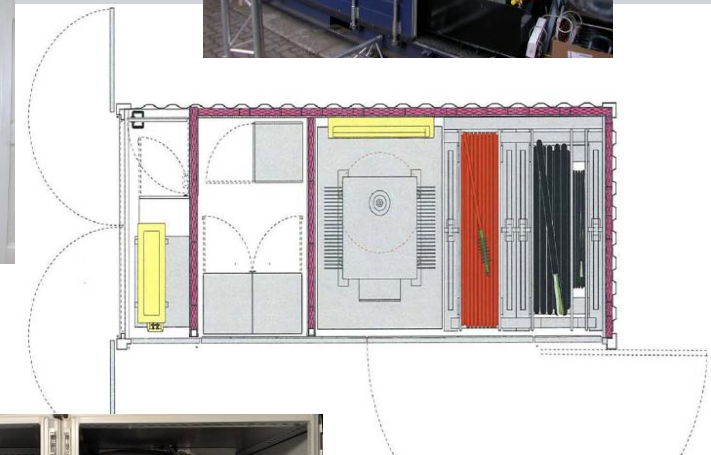


SMPS – Switch Mode Power Supply Mobile Test Unit

SIEMENS

The **Mobile Test Unit** is a flexible container solution to determine the potential for maximum ESP performance

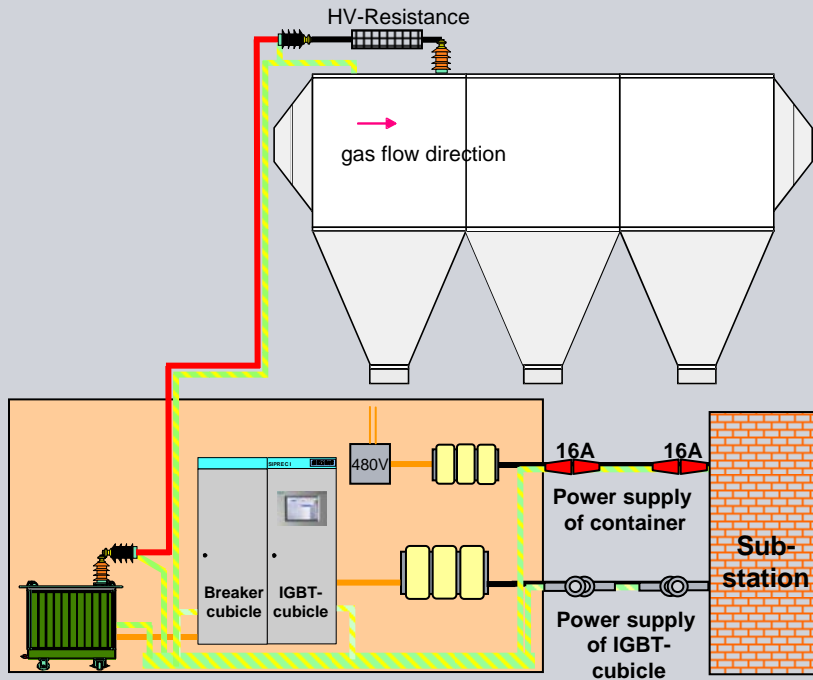
- Quick installation and de-installation
- All required equipment on board
- Existing system remains untouched
- Installation of test equipment independent of normal operation
- Only short interruption of operation to connect the high voltage feed
- Supply via high voltage ESP-cable
- Multiple containers in case more than one power supply required



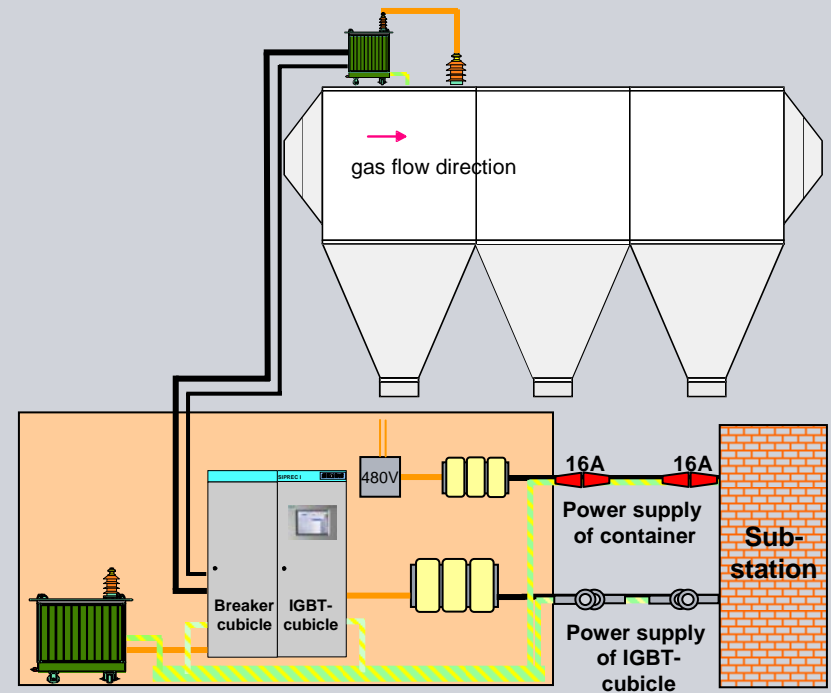
SMPS – Switch Mode Power Supply Possible Configurations



IGBT (500Hz)-operation with a new 60Hz-T/R-Set



IGBT (500Hz)-operation with the existing 60Hz-T/R-Set



Thank You for Your Attention

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