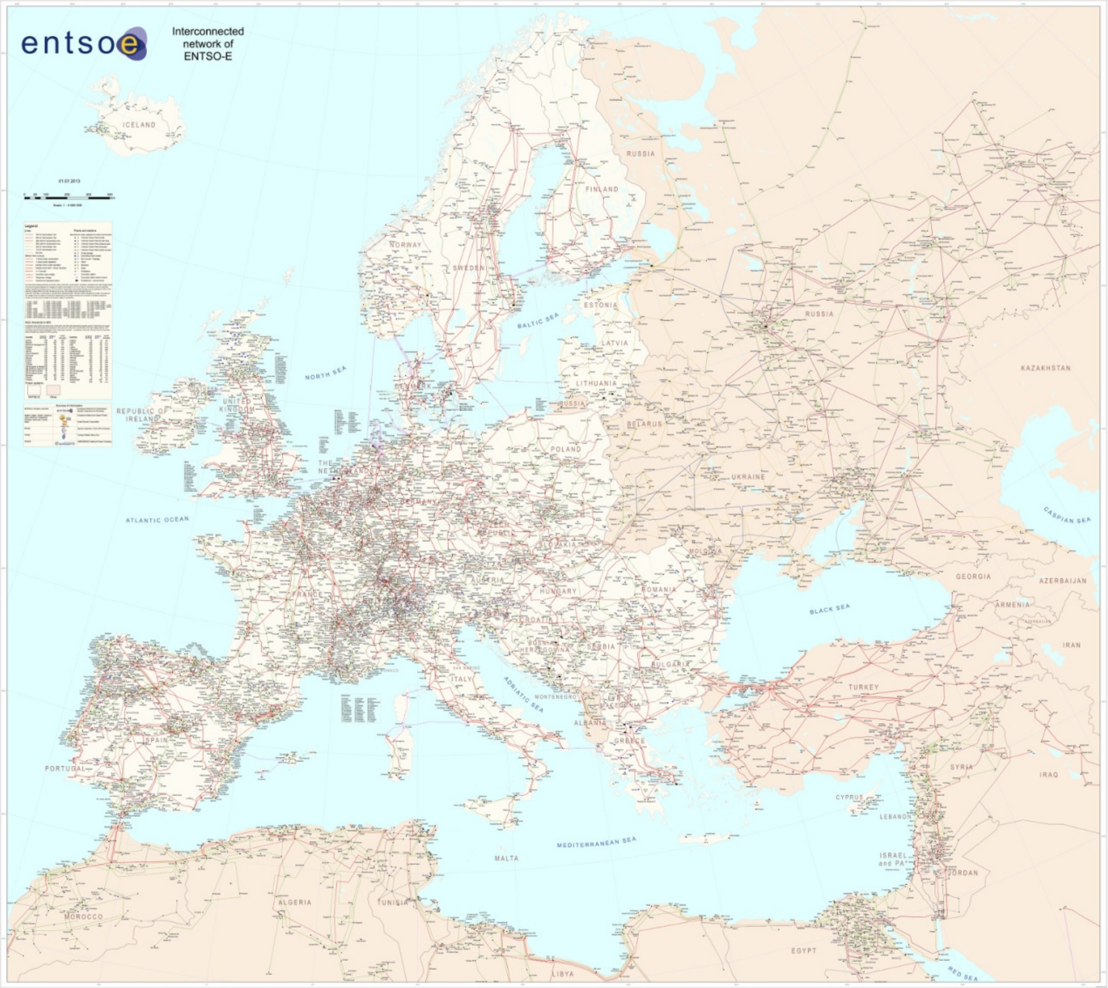
Siemens Corporate Technology | May 2014 | Dr. Tabea Arndt

High-Temperature Superconductor Technology Applications facing the challenges in Power Technology of today and tomorrow

Contents

Introduction

The UCTE (ENTSO-E) grid (14.May.2014)



Introduction

The HV grid in germany

The smaller the grid size and the weaker the grid control, the bigger the deviations in frequency.

As long as the energy generation is dominated by rotating machines (thermal, hydro and (partly) wind power plants), the generation-load mismatch will yield a change in frequency (change in rotational energy).

An inverter dominated generation has to be actively controled in such cases.

Norwegian Pearl

21:38-21:39: opening of HV link

Blackout on 04.Nov.2006
21:38-21:39: opening of HV link

Corporate Technology
RTC PET SUC-DE/ Tabea Arndt

UCTE grid separated

Split of UCTE grid after disturbance

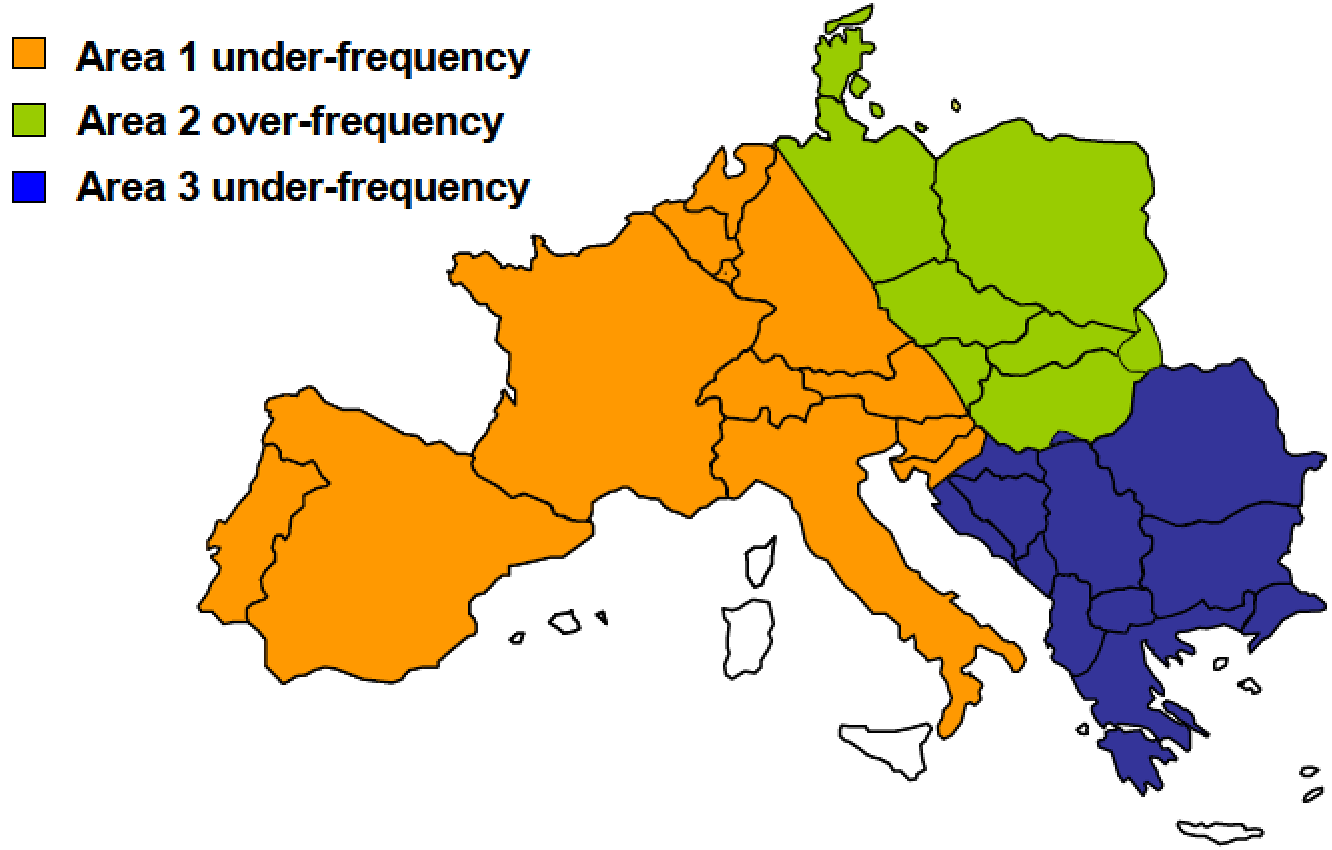


Figure 4: Schematic map of UCTE area split into three areas

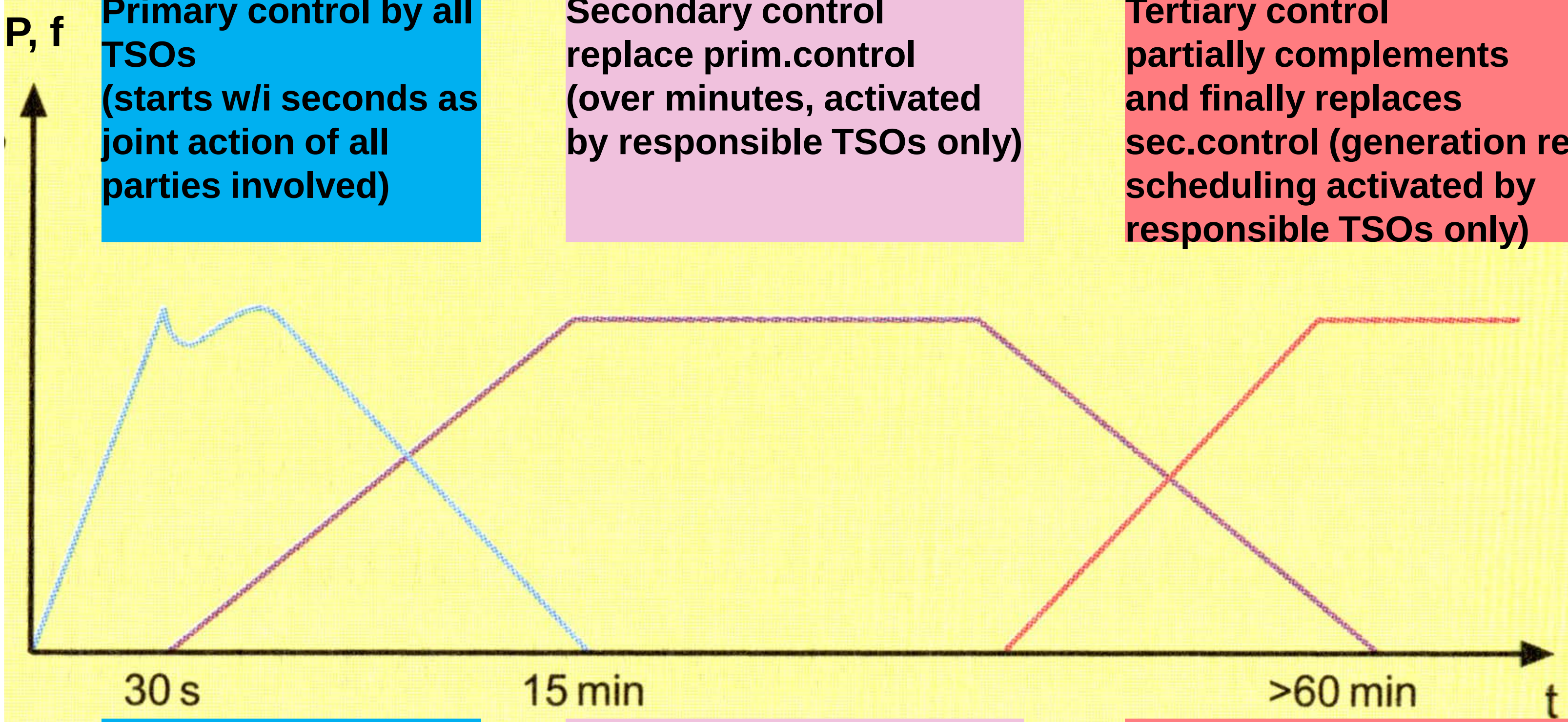
Grid control – frequency and power control

Three classes of control measures:

Primary control by all TSOs (starts w/i seconds as joint action of all parties involved)

Secondary control replace prim.control (over minutes, activated by responsible TSOs only)

Tertiary control partially complements and finally replaces sec.control (generation re-scheduling activated by responsible TSOs only)



done in & at all plants (>≈100 MW),
P-control
Total sum: ±3000MW

done on transmission level in areas by PI-control
e.g.: pumped hydro, GT‘s

done on transmission level in areas by PI-control
e.g.: pumped hydro, ST‘s, GT‘s (ΔP/min ≥2% P0)

For details: refer to Operating Handbook of UCTE, Policy 1: Load-Frequency-Control [2014050503]

Grid control – load shedding

In case of dramatic frequency drop, a multi-level load shedding plan will be executed, e.g.:

1. **Selected pumps will be shut-off**
2. **Randomly selected small areas of the grid will be disconnected**
3. **Shut-down of power plants (due to resonance risks)**
   → will increase risk of black-outs in some regions
4. **Dissolution of long-range grid connections,**
   resulting in smaller island grids

Corporate Technology
RTC PET SUC-DE/ Tabea Arndt

Angle differences in UCTE

22:00

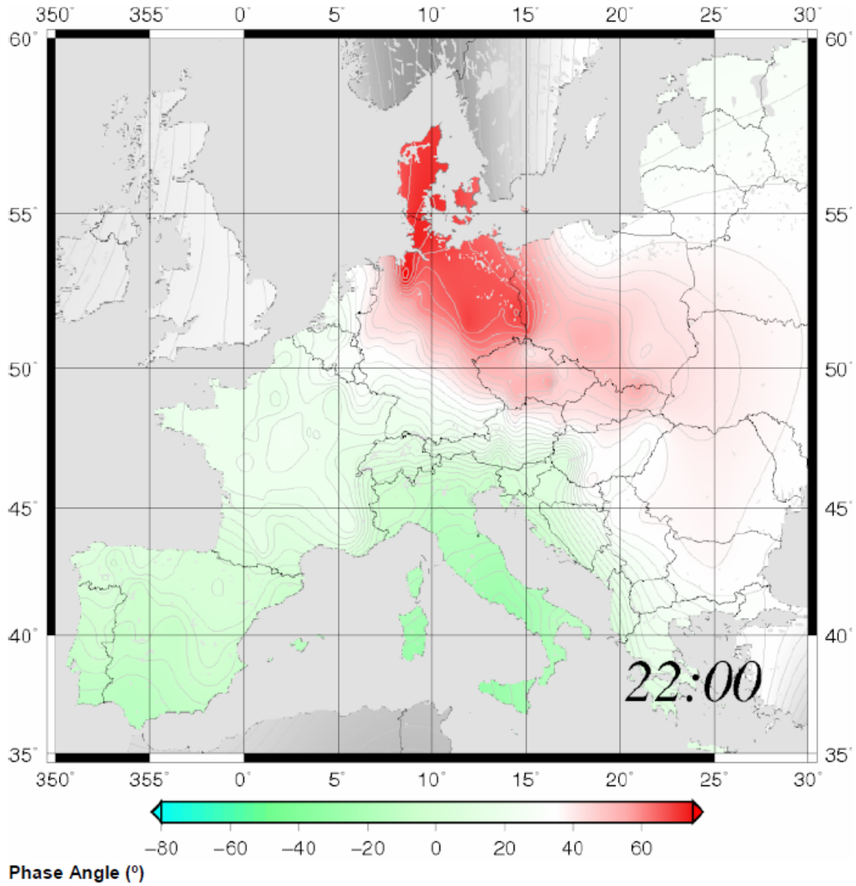
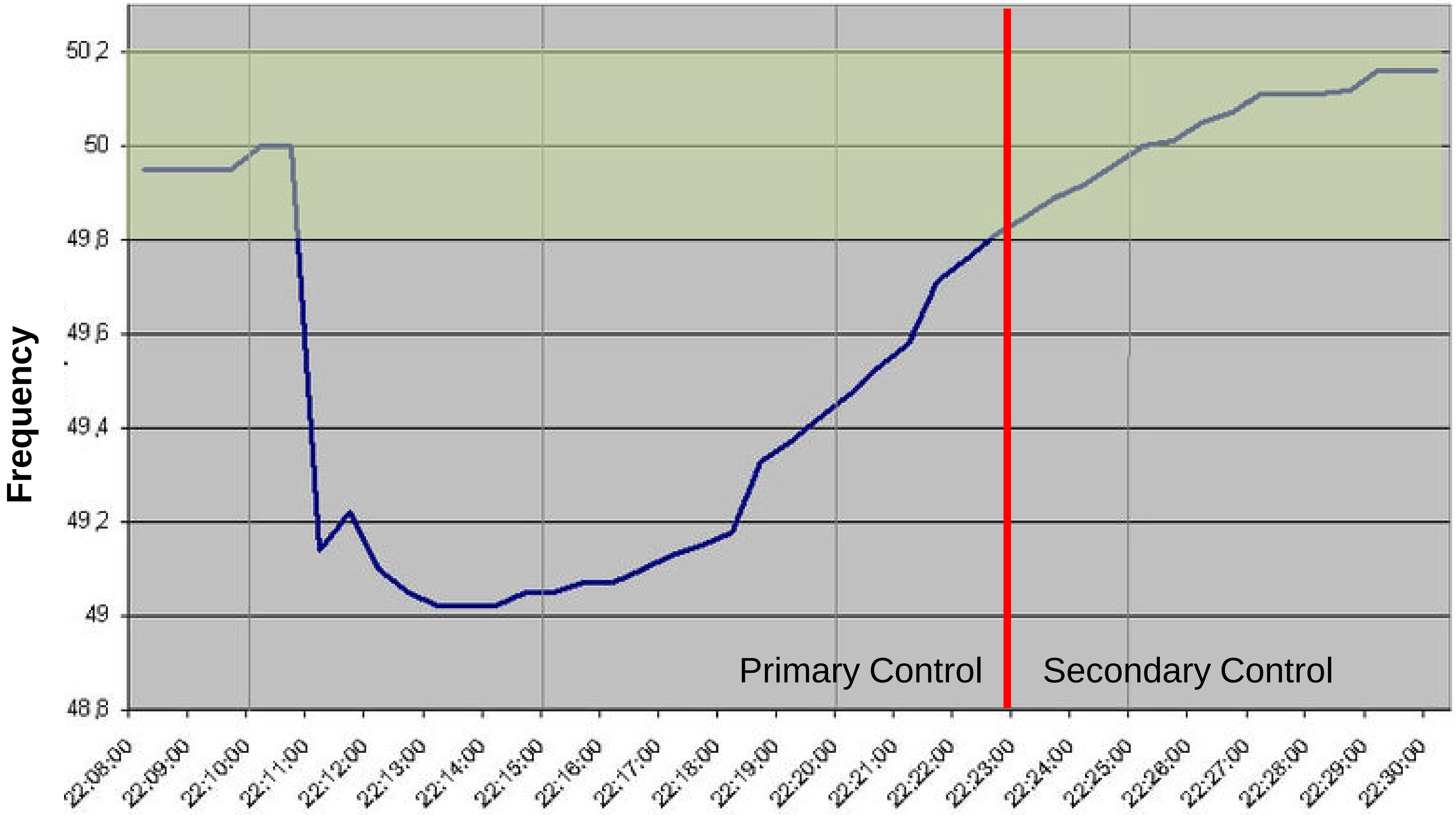


Fig. D1a: **Voltage phase angle differences in the UCTE system at 22:00 /ELES/**

Frequency stability of grid 04.11.2006

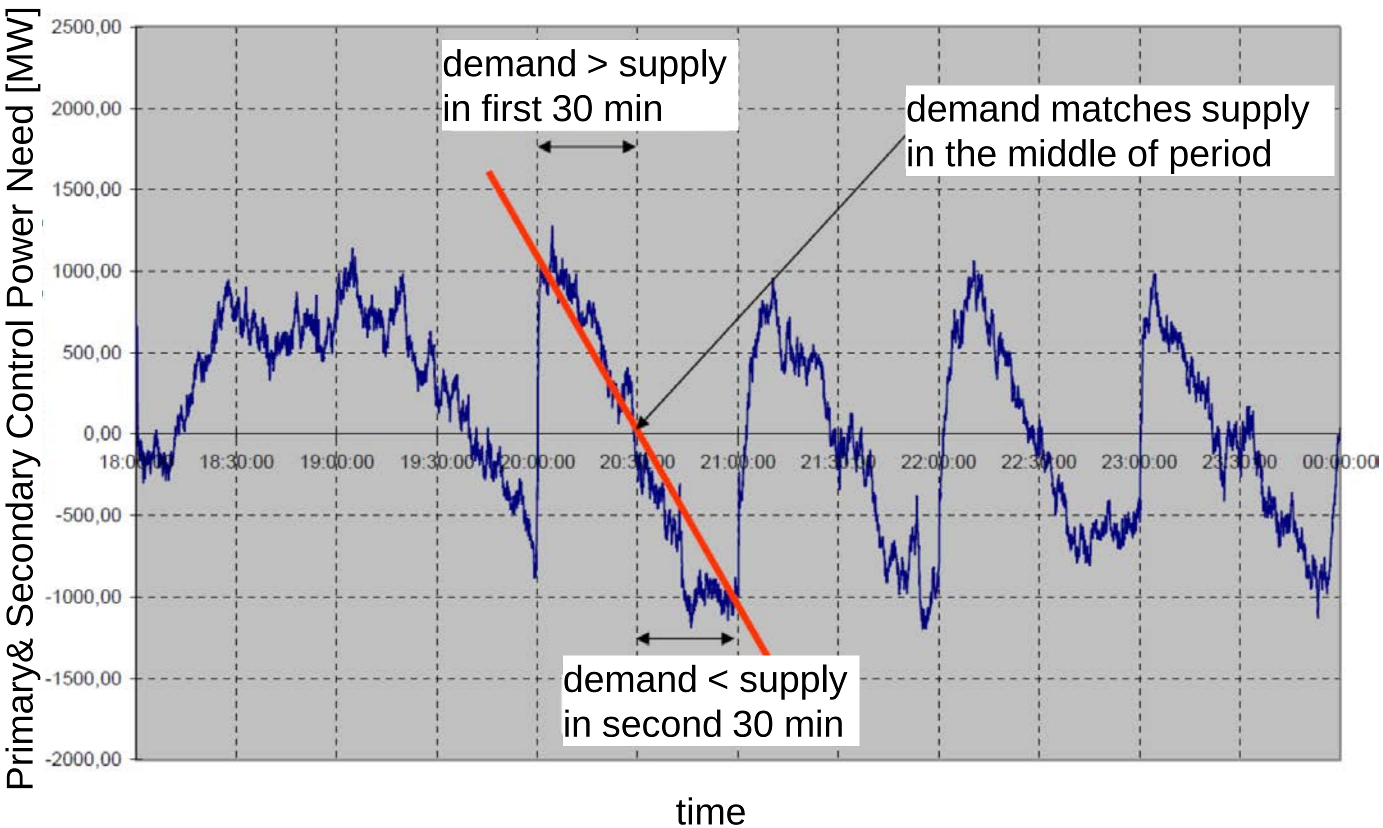
04.11.2006, 22:08- 22:30 MEZ (Ruhr area) (total generation in UCTE: 274 GW)



During disturbance: split of the european grid into 3 segments (this curve from area 1=western Europe)

Control Power in control area

24.02.2010, 18:00-00:00 MEZ (source TenneT TSO)



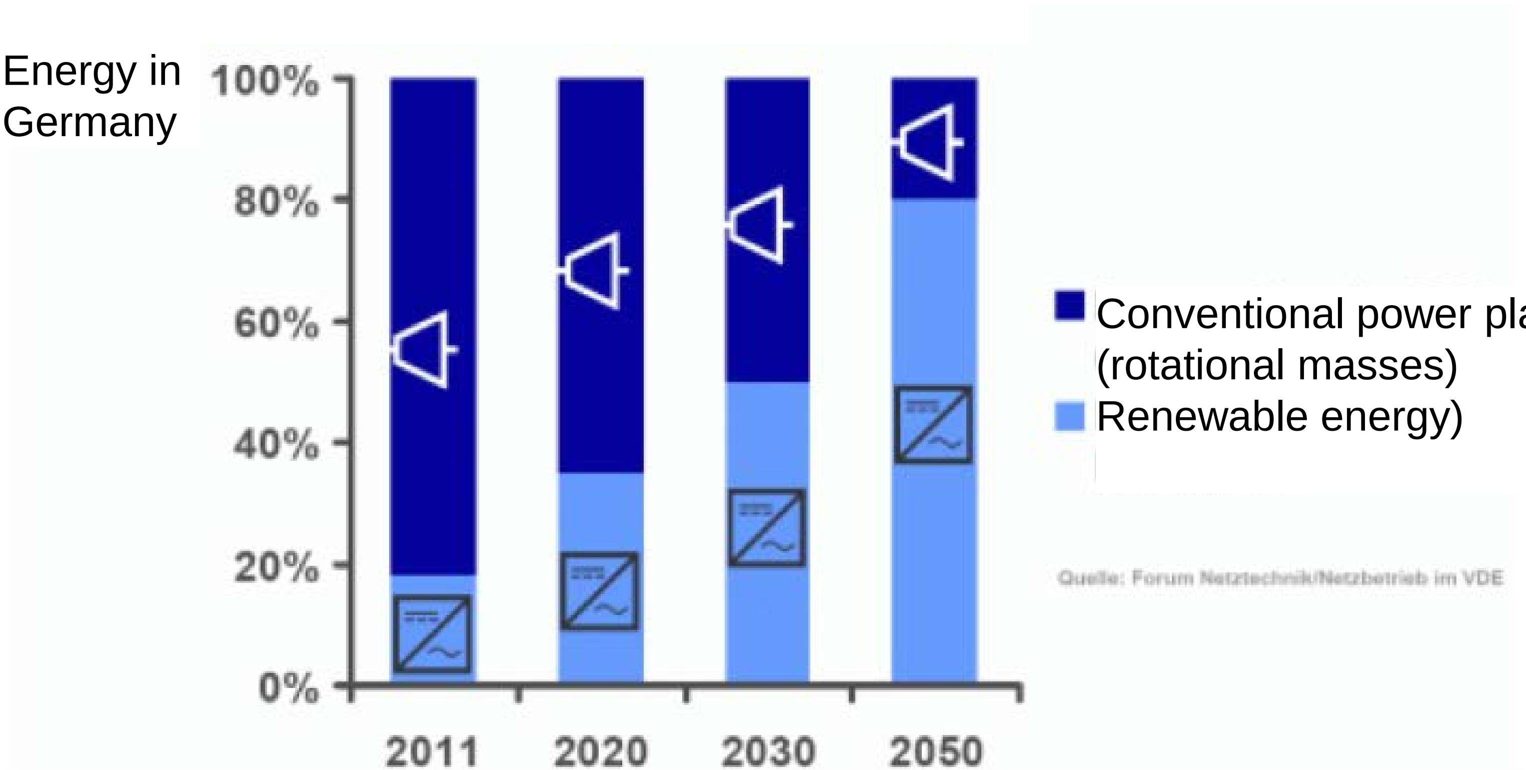
Corporate Technology
RTC PET SUC-DE/ Tabea Arndt

Challenge of increasing share of REN

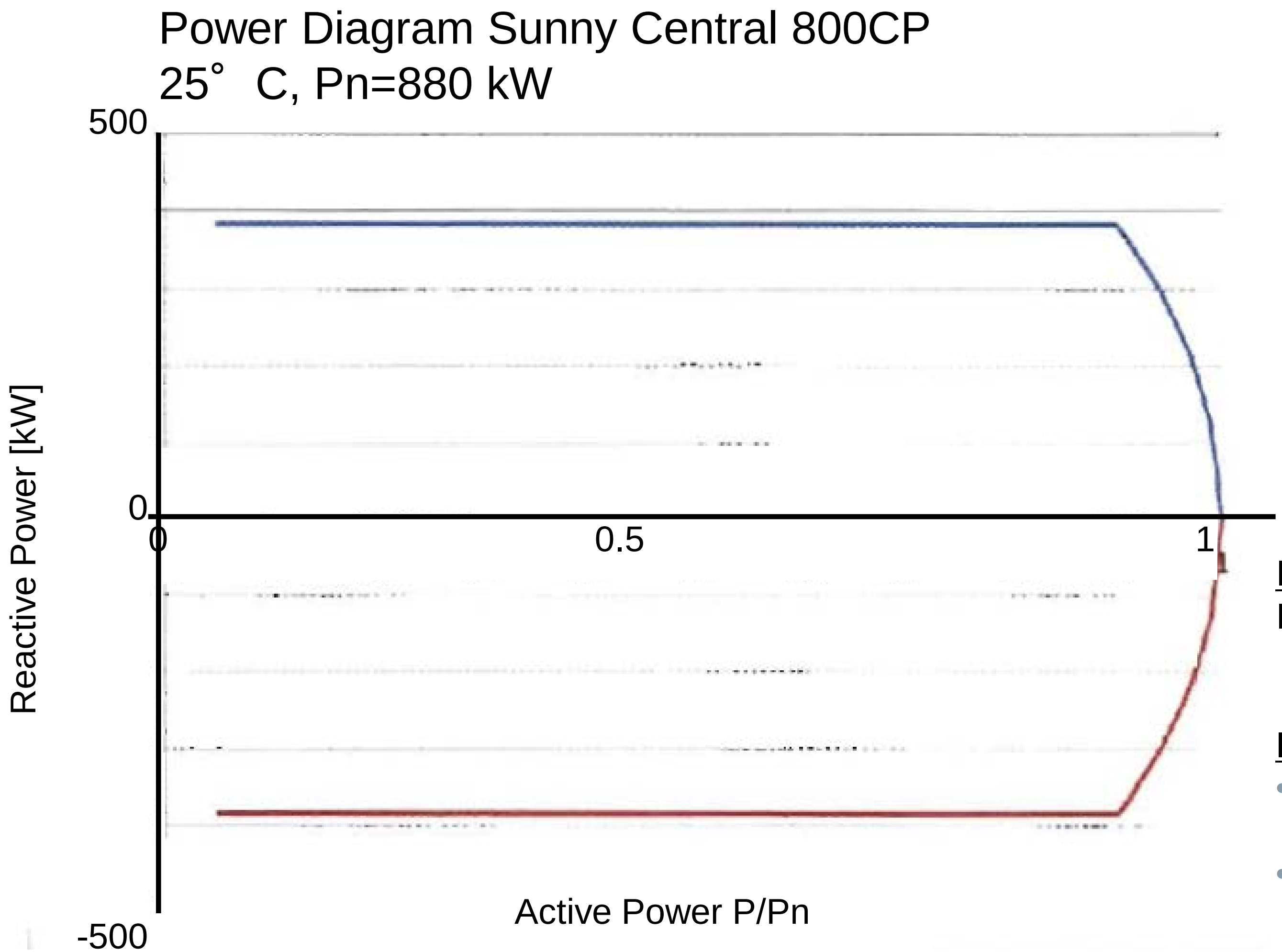
Power generation not only on HV level, but increasingly on MV level,

e.g. 30kV introduced by WindPower.

≈16 GW installed PV on MV in 2010 in Germany



Real inverters capabilities



<u>In theory:</u>

Inverters have „unlimited capabilities“

<u>In reality:</u>

- You have to teach (control) them
- Real products are limited/ optimized for thermal reasons

Local Power Generation in Hong Kong

Location of local power stations in Hong Kong

 Corporate Technology RTC PET SUC-DE/ Tabea Arndt

Confined Power Grids
Hong Kong

An example of an extended, but (almost) confined power grid

Confined Power Grids
Hong Kong

Tunnels for 275 kV power transmission lines:

3.1 km
5.7 km
0.8 km
0.8 km
0.2 km
0.1 km

Confined Power Grids
Hong Kong

Scene of boundary conditions

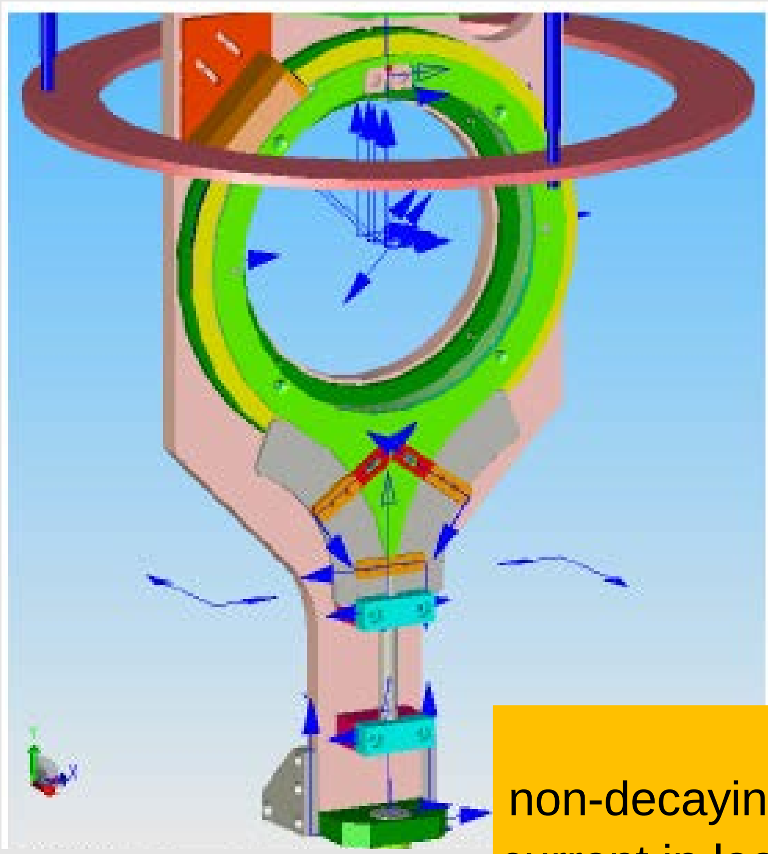
Power Station	275 kV, 132 kV (underground) 400 kV, 132 kV (underground)	Load Center Zone Substation 4x 40 MVA XFER → 4x 60 MVA XFER (SF_6 filled)	11 kV, 22 kV 11 kV, 33 kV	Substation (>3700#)	380 V, 220 V

Oil free substation Shaukeiwan

IFC2 on 70th floor (293 m over ground): **highest substation of the world**

Taipeh MegaTower

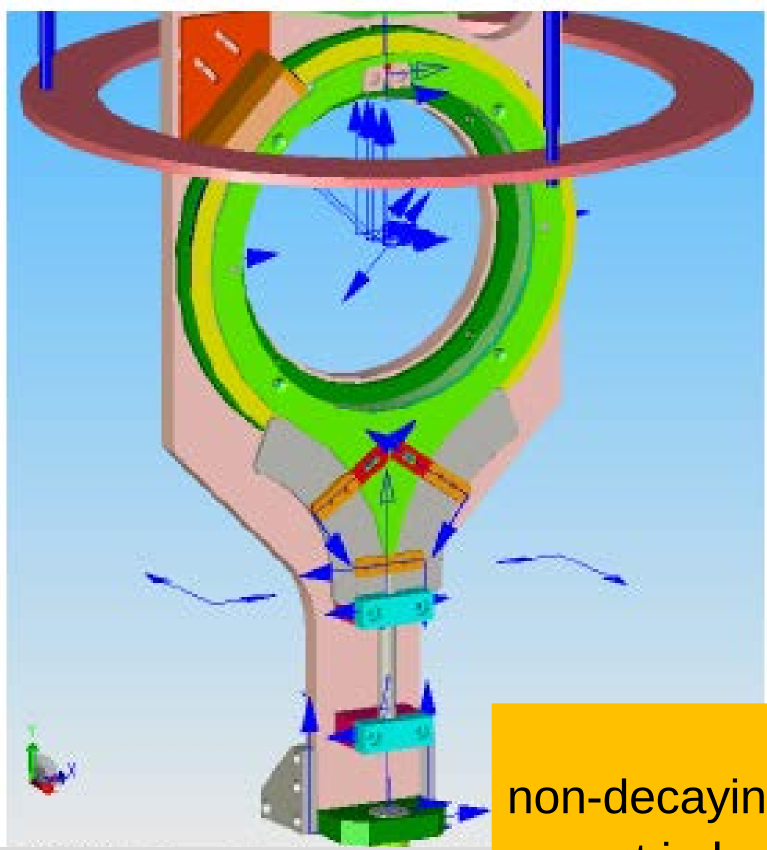
1(3) unique key properties of Superconductors: persistent mode capability



non-decaying current in loop

MRI

1(3) unique key properties of Superconductors: persistent mode capability



non-decaying current in loop

passive HTS bearing
(Test-Rig for 5kN-bearing)

2(3) unique key properties of superconductors: outstanding current densities

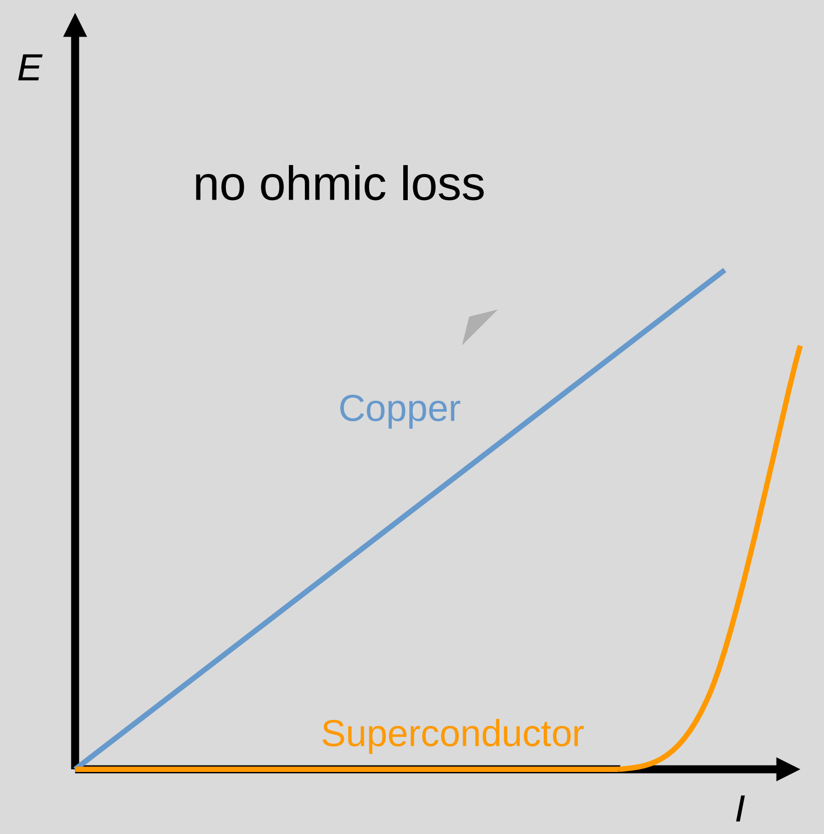
Copper
>100 mm² for
500 A

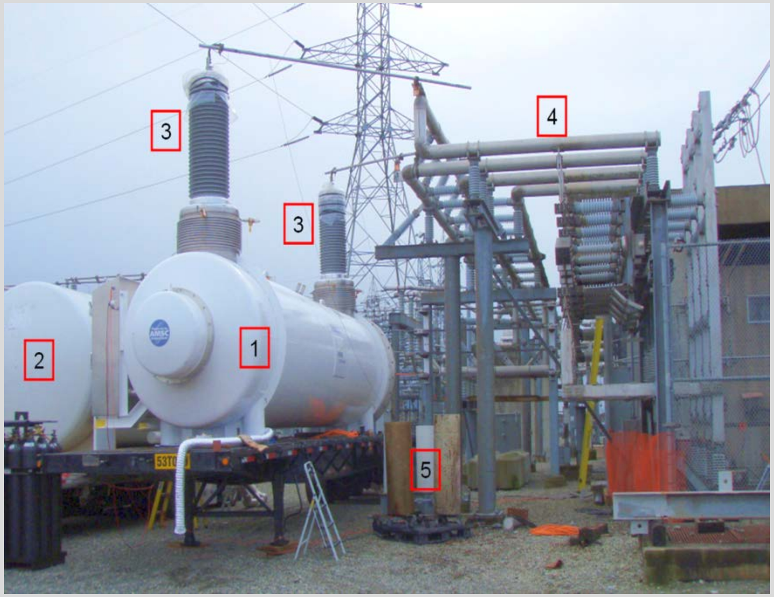
HTS
<1 mm² for
500 A

no way to transport more current in a smaller cross section

Power Plant Generators
(e.g. conventional technology of 2GW weights 750 tons)

3(3) unique key properties of Superconductors: lossless current transport



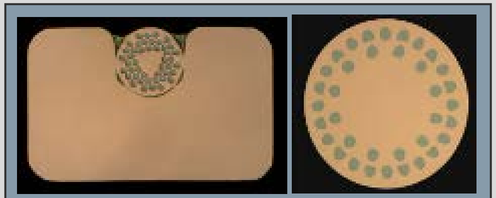


1: SFCL

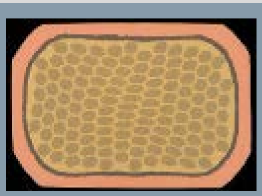
2: LN_2 refill tank, 3: bushings, 4: busbars, 5: voltage transducer

Superconducting Technical Wires

Low Temperature Superconductors

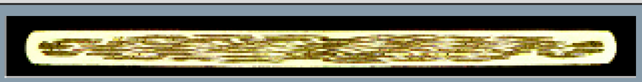


NbTi (4.2K, ...10T)



Nb_3Sn (4.2K, ...22T)

High Temperature Superconductors



1. Generation wire (Bi2223) = 1G

2. Generation tape (RE123) = 2G

Mid Temperature Superconductors

1. Generation wire MgB_2
(4.2K, >10T) , (10...30K, <2T)

2. Generation tape MgB_2
(4.2K, >10T) , (10...30K, <2T)

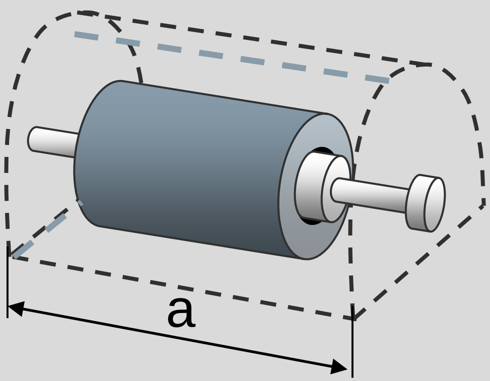
?

(Magnet applications)

(Power Applications)

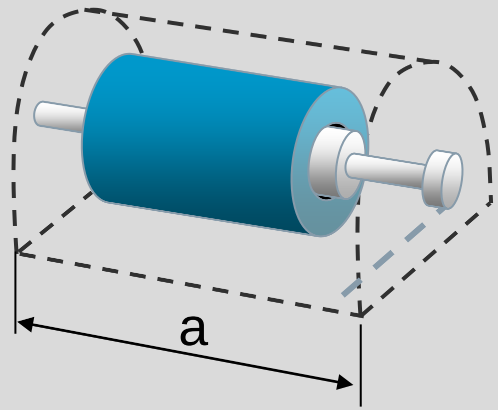
Comparison of rotating machines

conventional machine



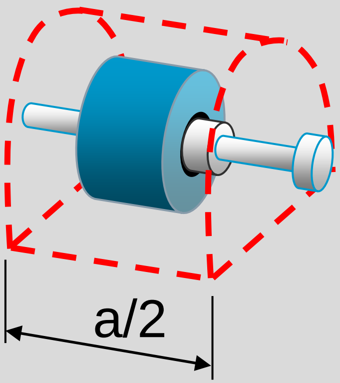
- Power rating 100%
- Loss 100%
- Ageing rotor winding
- Limited power diagram

HTS Rotor with conventional Stator (Retrofit)



- For new apparatus or rotor retrofit
- Power uprating >115%
- ≈50% loss
- No ageing in the rotor
- extended power diagram
- Little more CAPEX

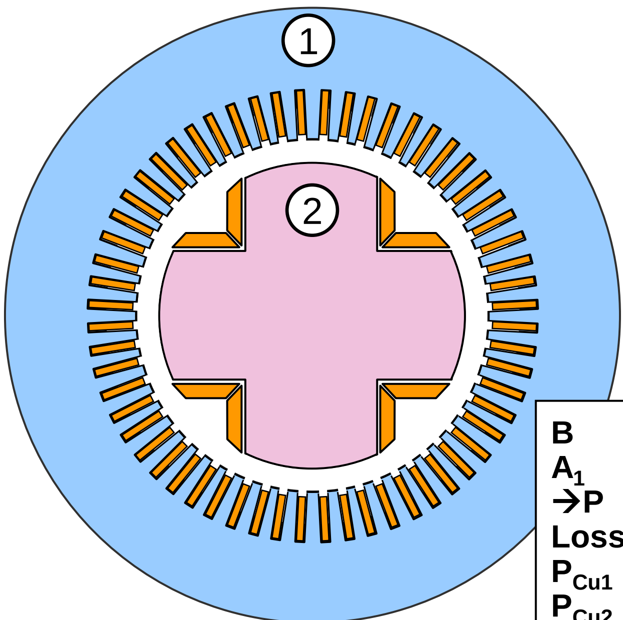
HTS Rotor with air-gap winding stator (High power density)

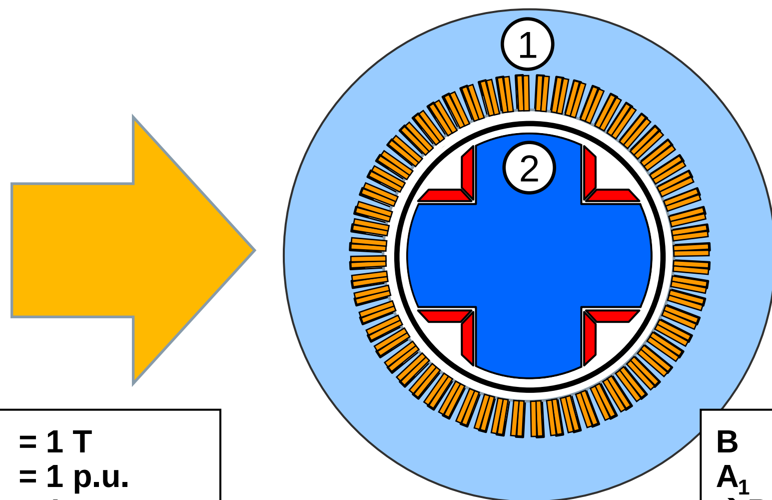


- Totally integrated design harvesting all benefits
- Power uprating >115%
- <50% loss
- No ageing in the rotor
- unlimited power diagram
- Improved electrical stability
- Higher CAPEX

Power Generation -
Properties of generators based on HTS

<u>Just to recall:</u> First approach to introduce HTS in rotating machines is using a field winding made of HTS





B = 1 T
A_1 = 1 p.u.
→P = 1 p.u.
Losses:
P_{Cu1} = 1 p.u.
P_{Cu2} = 1 p.u.
P_{Fe} = 1 p.u.

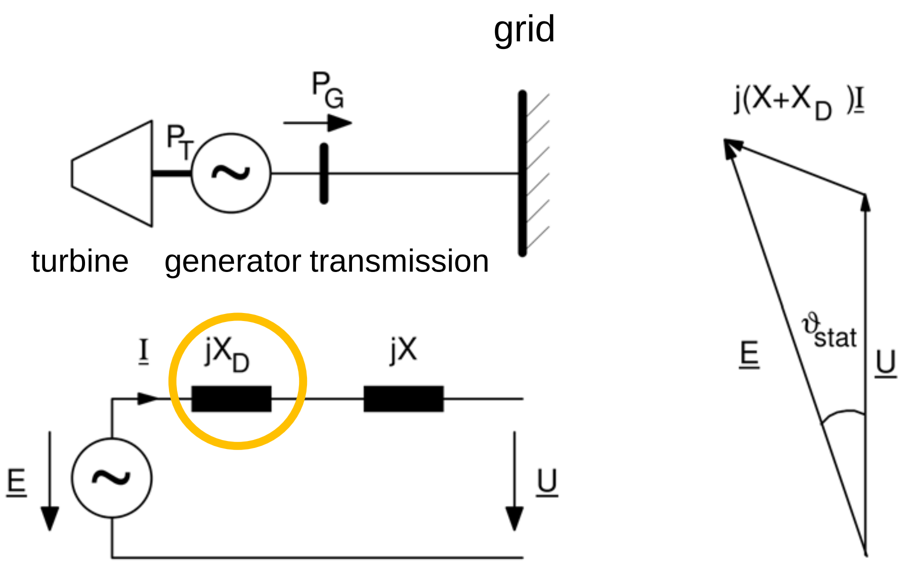
B ≈ 2 T
A_1 ≈ 2 p.u.
→P ≈ 4 p.u.
Losses:
P_{Cu1} = 2 p.u.
P_{Cu2} = 0 p.u. +
$P_{Cooling}$
P_{Fe} = 0.6 p.u.

<u>Conventional Cu based design:</u>
- Laminated stator core with teeth
- Copper windings in stator and rotor
- Warm rotor iron

<u>HTS based design:</u>
- Laminated stator core without teeth
- High density Cu stator winding
- HTS rotor windings
- Round and smooth Cryostat
- *Cold rotor iron design (no must)*

Power Generation -
Properties of generators based on HTS

Large airgap, small inductance results in small x_D-values (0.2…0.5 pu)



→ HTS generators are very good voltage sources!

HTS Transformers – improving the best…

Aspects:

- Hard to beat conventional transformers as long as no special features are requested
- 1…100 MVA transformers
  (offset for Cryo-technology determines smallest reasonable rating)
- Cooling by LN2, not oil, environmentally benign
  → decreased fire hazard
- reduced volume/ weight
  → 50…70% (with efficiency ≥99% (incl. cooling))
- No aging

Challenges:

- high inrush & short current capability required → SFCL needed?!
- Recooling considerations/ ride through

Power Transmission Lines

Aspects:

- Uprates capacity of existing ducts (≈3x)
- Might allow removal of transformers/ voltage levels
- Environmentally benign (LN_2-cooling, waste heat, stray field, loss(?))
- Lower impedance – less “visible” in grids (but take care!)
- Best to combine with a SFCL

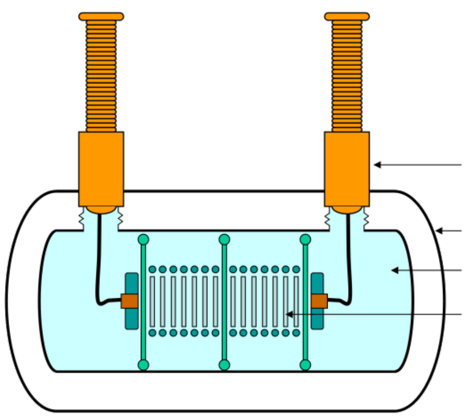
Challenges:

- Excess currents
- Risk of N_2-concentration → execute measures
- High component cost (wire, cryostat, cooling)
- Load fraction determines application/ business case
- Cool down time

Corporate Technology
RTC PET SUC-DE/ Tabea Arndt

SFCL - Superconducting Fault Current Limiters
„the unfair competitive advantage“

Resistive Type FCL



Aspects:

- **Invisible in normal operation**
- **Immediate response (“speed of light”)**
- **No trigger needed – only sensing equipment**
- **Allows safe and full use of conventional devices**
- **Steady cooling needed**
  (but power less than loss of conventional equipment)
- **Loss in bushings**

Challenges:

- Recooling considerations/ ride through
- Combination of cryogenics, high currents and voltages
- Consider transient current needs

1G HTS

- feasible

2G HTS

- Customized & optimized architecture

SFCL –
Superconducting Fault Current Limiters

„ASSiST“ SFCL in Bavaria (grid of Stadtwerke Augsburg), Partners: SWA & Siemens

Project expects approval!

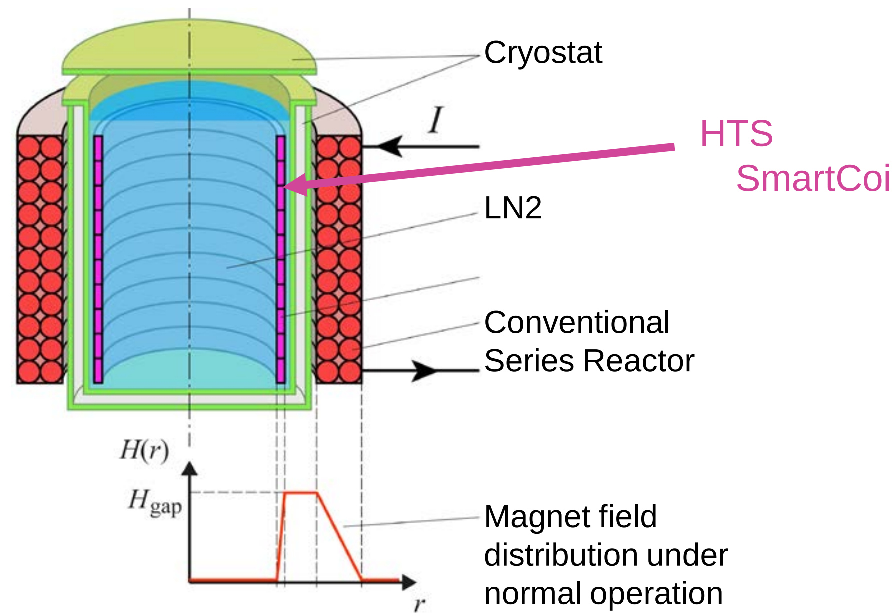
Project and technology background

- Integration of MTU’s extended testing facility of combined heat and power unit (CHP) requires extreme reduction of short-circuit current
- Combination of SFCL with fast breaker and parallel series reactor

Project goal and customer benefit

- Design, construction and long term field test of a 15 MVA SFCL demonstrator
- Reduction of loss compared to conventional solution with series reactor
- Increased system stability
- Abandonment of large area breaker up-grade
- Reference and market testing project of SFCL

Fault current limiters
„SmartCoil“ – a fair add-on advantage „introfit“



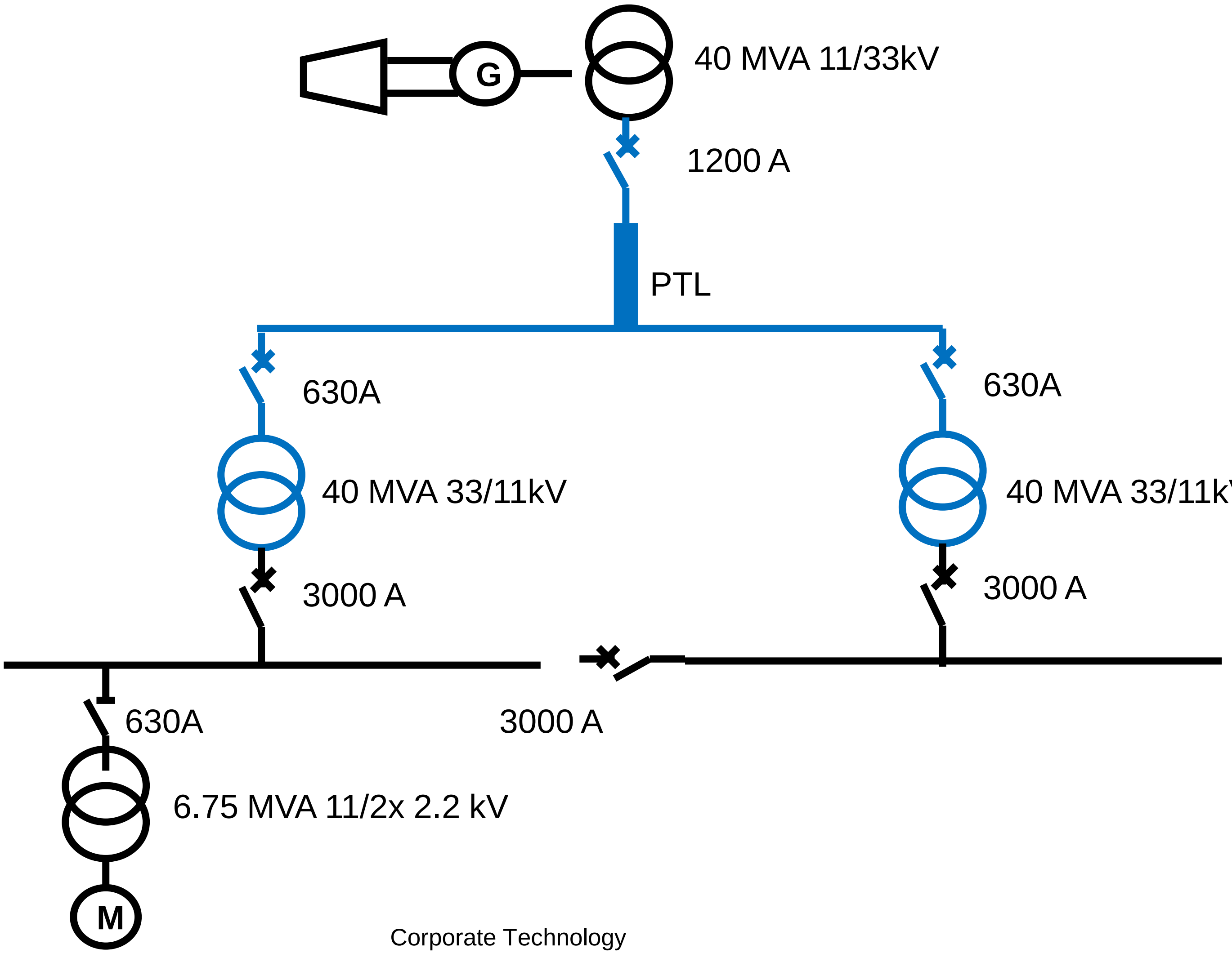
Project expects approval!

Aspects:
+ No bushings (no thermal or electrical input)
+ Intrinsic fail safe
+ retrofit approach
- Large volume
- Large size
- Relatively low limiting capability

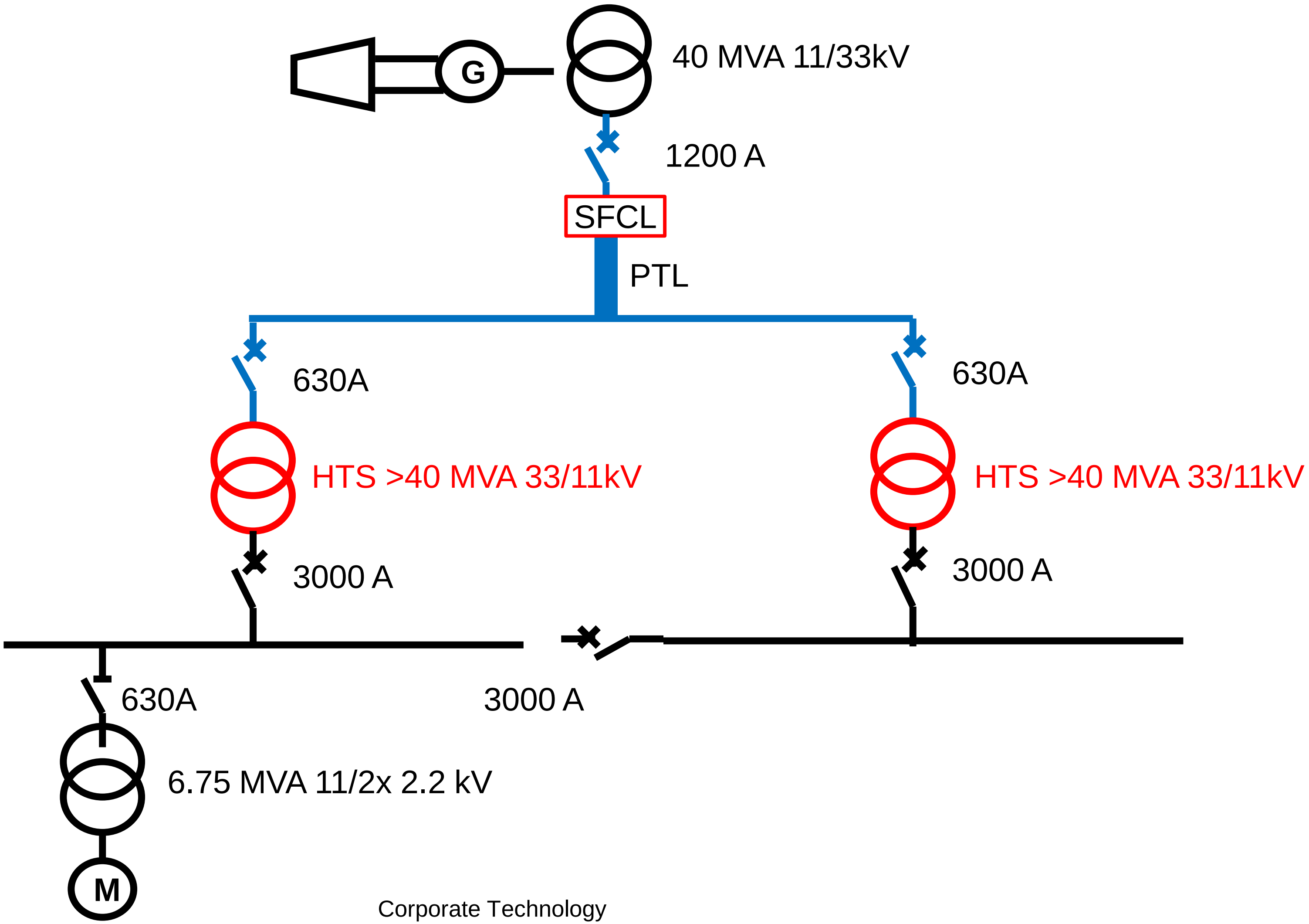
Motors

→ Refer to the generators, dynamic benefits and insensitiveness to load

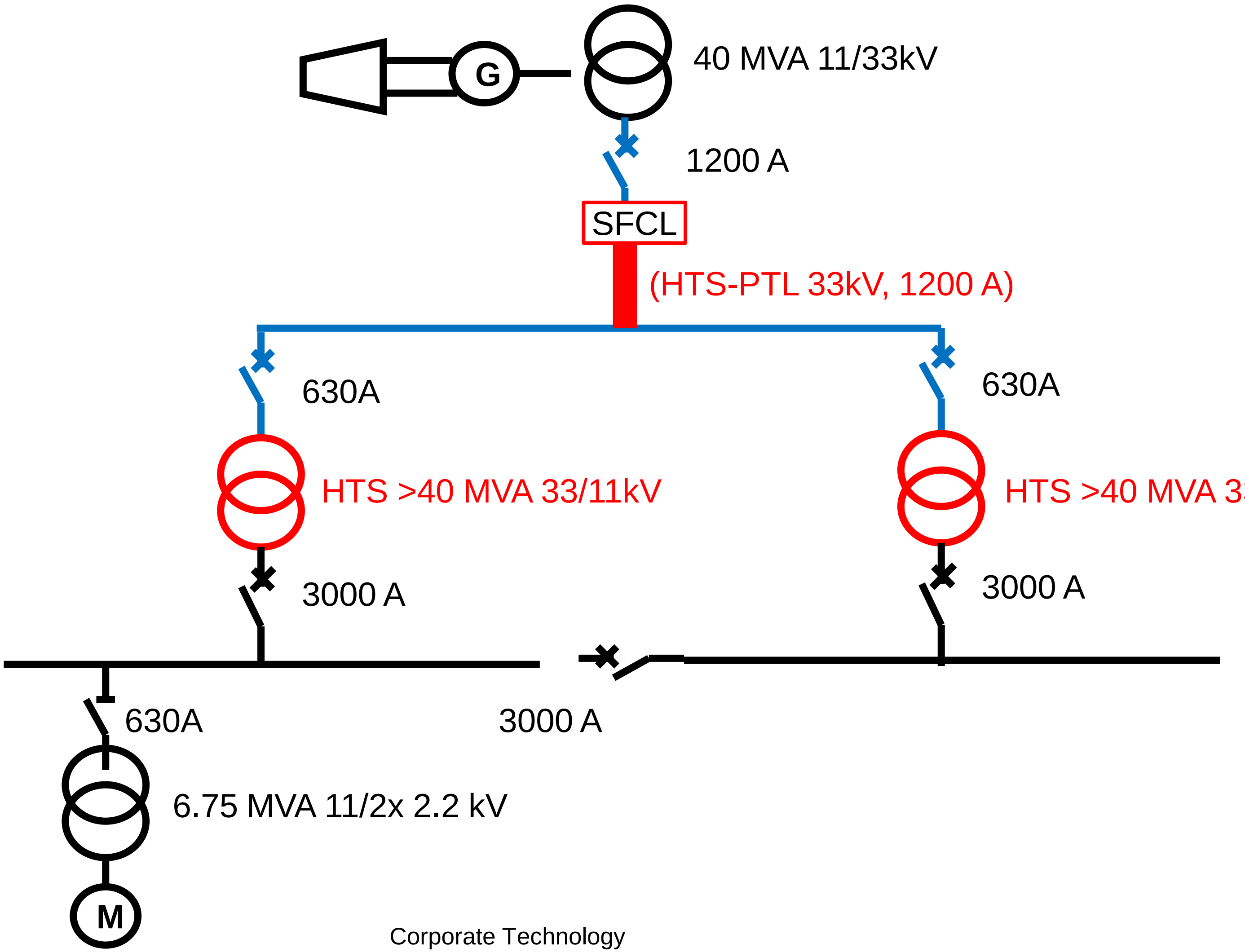
Confined Power Grids, selected section – Scenario#1: conventional equipment



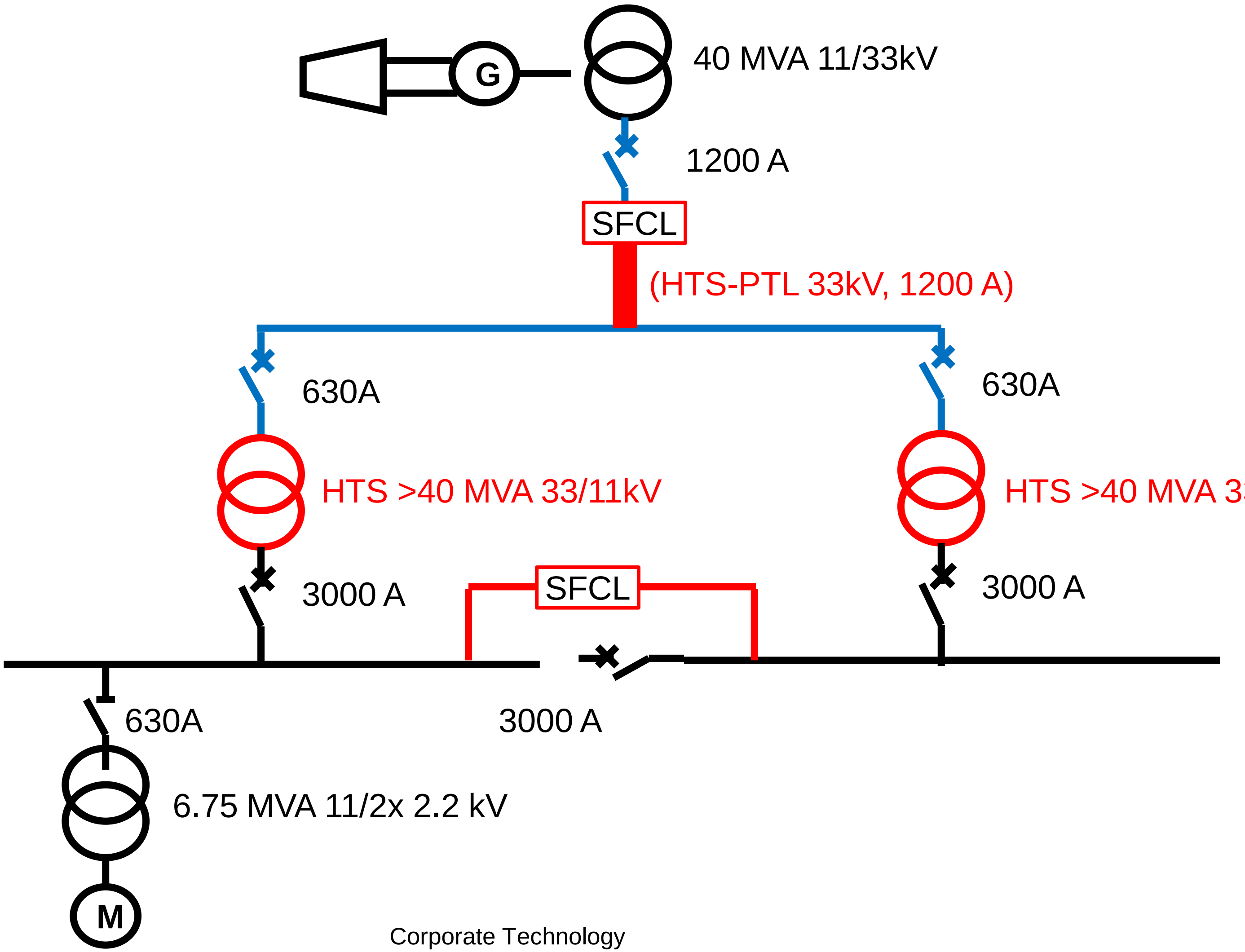
Confined Power Grids, selected section – Scenario#2: SFCL+ uprated HTS-XFERs



Confined Power Grids, selected section – Scenario#3: uprated XFER and potential PTL

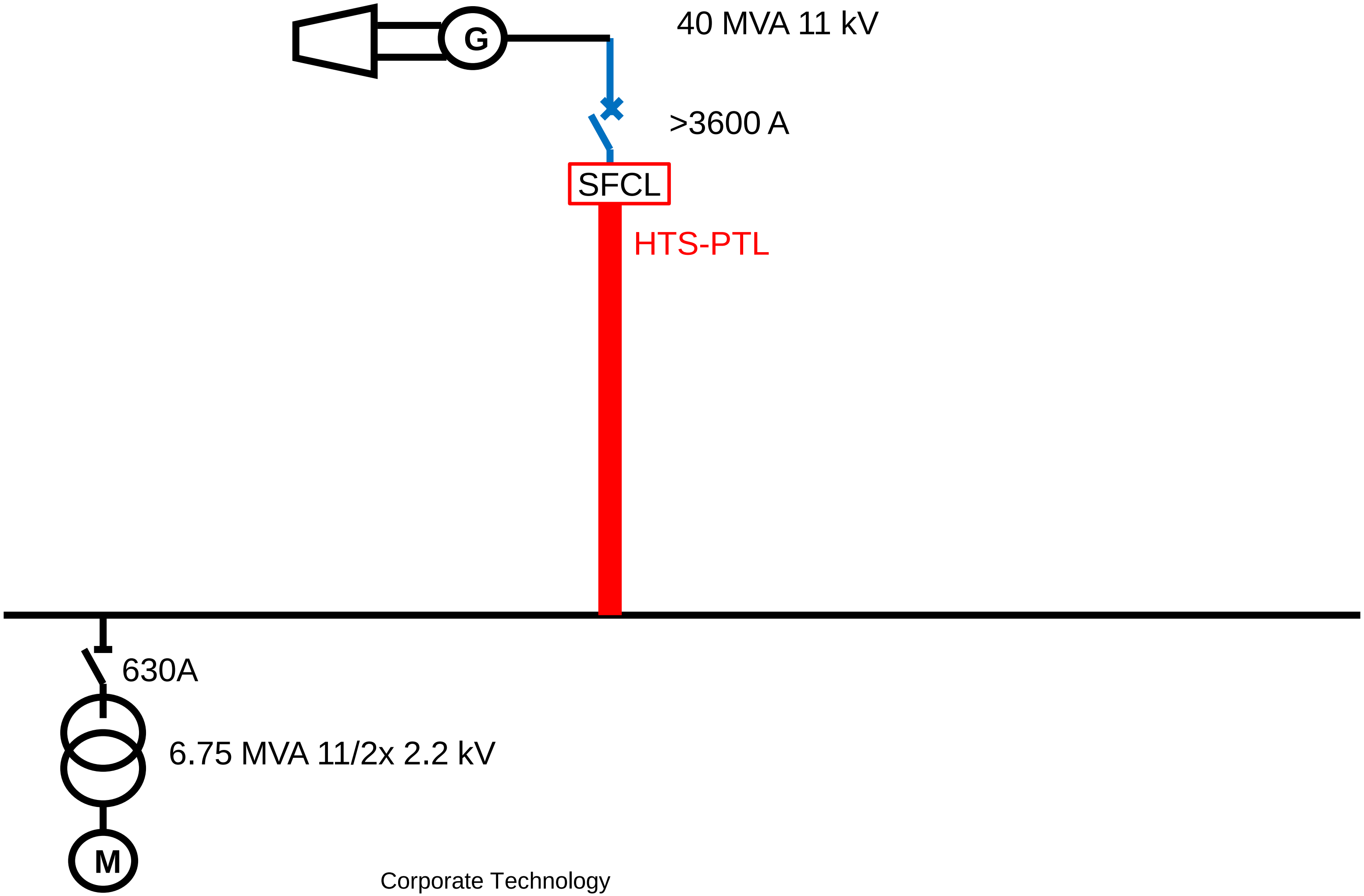


Confined Power Grids, selected section – Scenario#4: uprated XFER and busbar joining



Corporate Technology
RTC PET SUC-DE/ Tabea Arndt

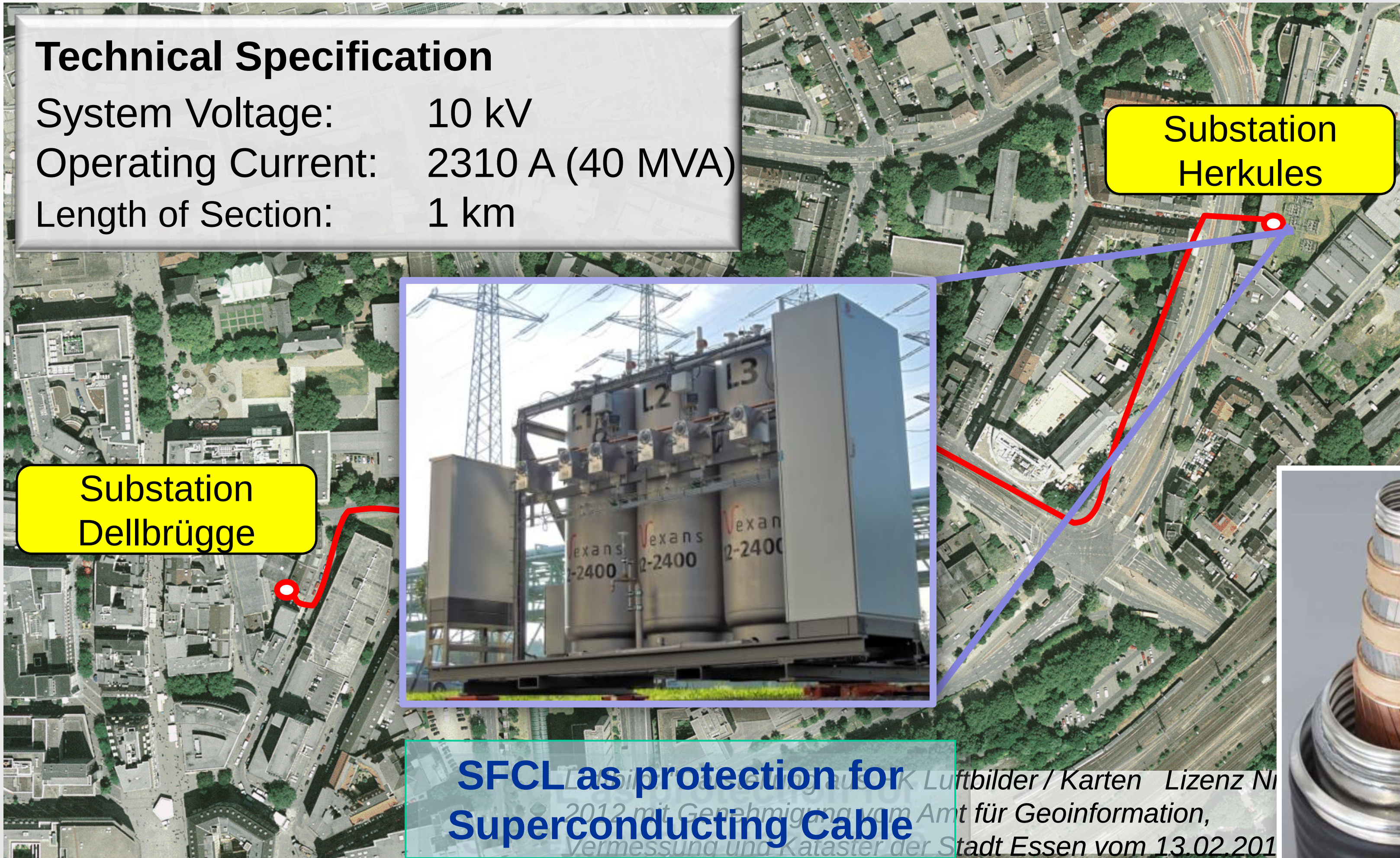
Confined Power Grids
Scenario#5: minimum device HTS approach



AmpaCity
SFCL 12-2400 in the City Grid

Technical Specification

System Voltage:	10 kV
Operating Current:	2310 A (40 MVA)
Length of Section:	1 km

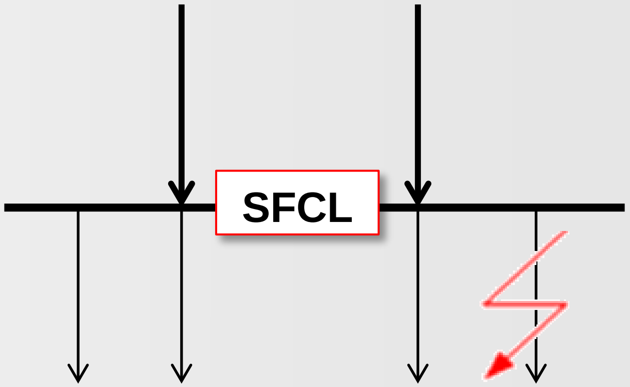


SFCL as protection for Superconducting Cable

New Installations
SFCL 12-1600

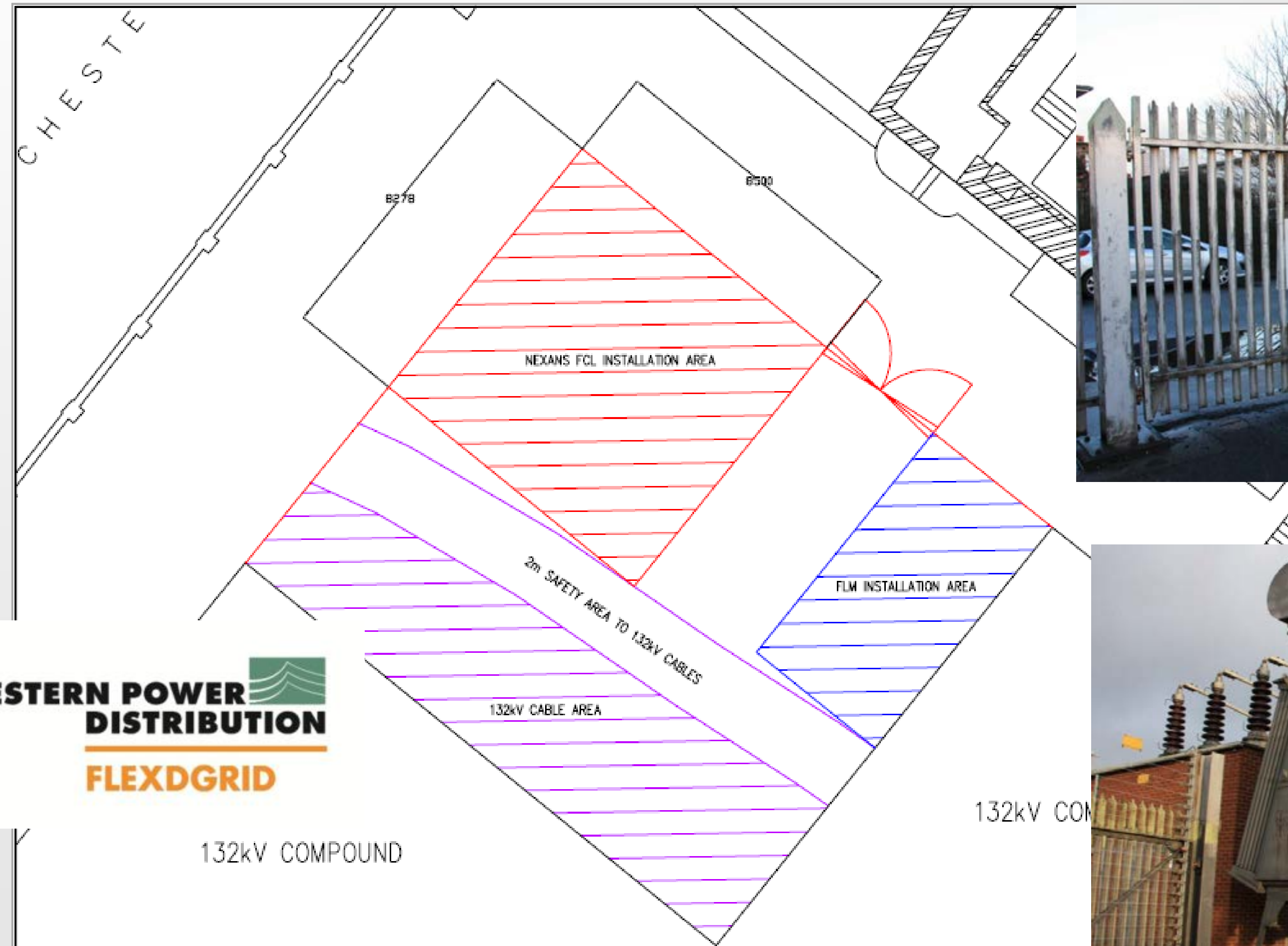
Installationsite: Chester Street 132/11 kV

SFCL 12-1600	
Nennspannung	12 kV
Nennstrom	1600 A
max. prosp. KS-Strom (peak)	20 kA
max. begrenzter Strom (peak)	9,9 kA
System-Begrenzungszeit	100 ms
Rückkühlzeit	< 30 s
Stehwechselspannung	28 kV
Blitzstoß	95 kV



New installations SFCL 12-1600

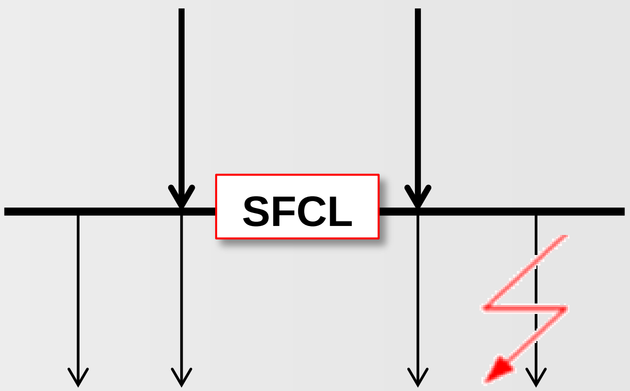
Installationsite: Chester Street 132/11 kV



New installations SFCL 12-1050

Installationsite: Bournville 132/11 kV

SFCL 12-1050	
Nennspannung	12 kV
Nennstrom	1050 A
max. prosp. KS-Strom (peak)	21 kA
max. begrenzter Strom (peak)	7,7 kA
System-Begrenzungszeit	100 ms
Rückkühlzeit	< 30 s
Stehwechselspannung	28 kV
Blitzstoß	95 kV

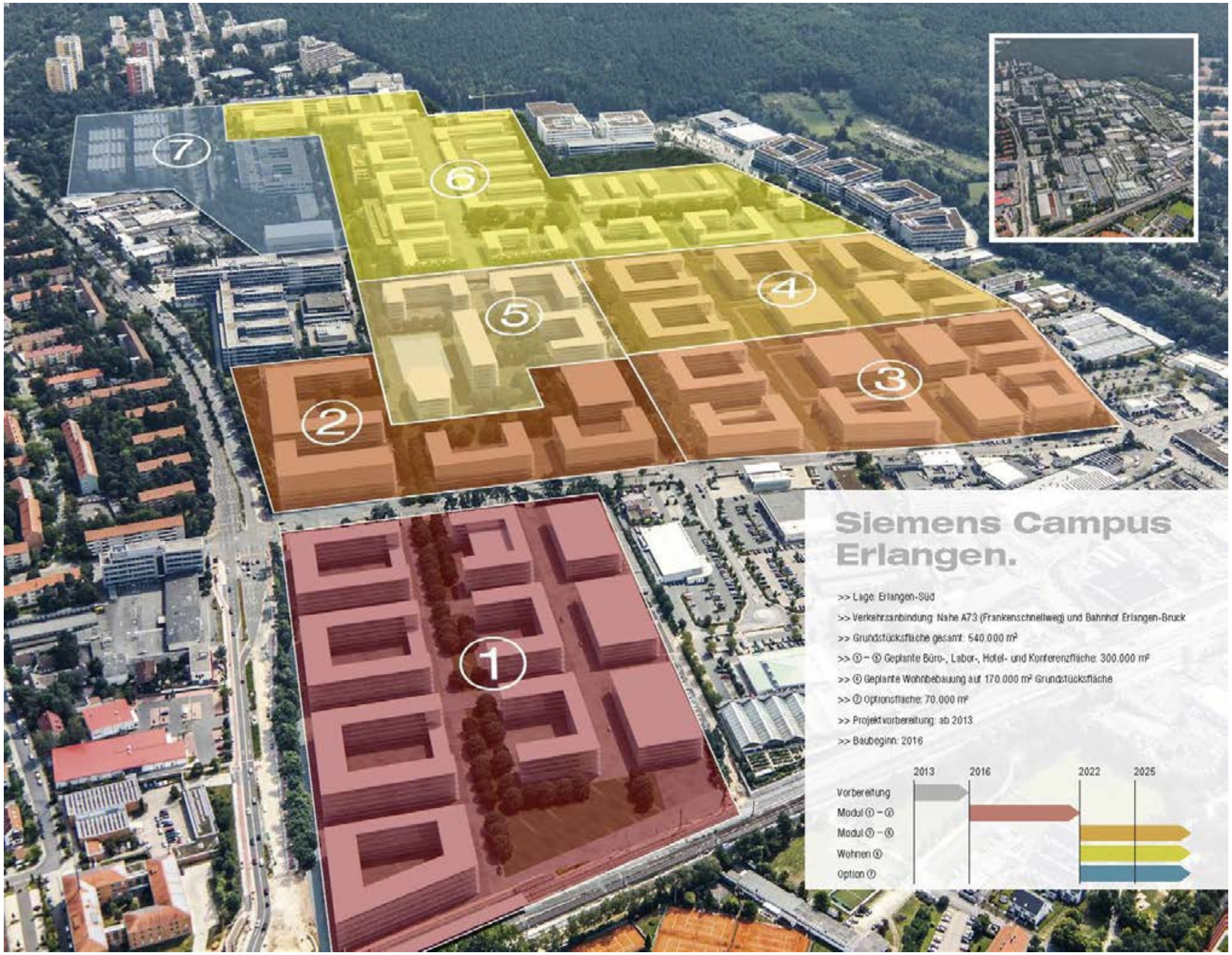


WESTERN POWER DISTRIBUTION
FLEXDGRID

Installationsite: Bournville 132/11 kV

WESTERN POWER DISTRIBUTION
FLEXDGRID

Siemens Campus Site Erlangen



Siemens will build new campus site in Erlangen until 2025+ (500'€)

Furthermore:
Project Campus Future Energy Systems as a part of the general Campus

 Corporate Technology
RTC PET SUC-DE/ Tabea Arndt

Conclusions

When looking for the USP (unique selling points), confined power grids (e.g. public, industrial, dedicated sites like hospitals,…) offer special opportunities for first-in-field HTS power applications due to additional requirements in

- Power density
- Uprates
- Efficiency
- Environment
- Weight
- Space
- Dynamics, stability

Using tactics like „retrofit“ or „introfit“ will be helpful.

Policies heading for energy efficiency, increased share of REN & “green devices” will give additional momentum to HTS devices.

Thank you

Disclaimer

This document contains forward-looking statements and information – that is, statements related to future, not past, events. These statements may be identified either orally or in writing by words as “expects”, “anticipates”, “intends”, “plans”, “believes”, “seeks”, “estimates”, “will” or words of similar meaning. Such statements are based on our current expectations and certain assumptions, and are, therefore, subject to certain risks and uncertainties. A variety of factors, many of which are beyond Siemens’ control, affect its operations, performance, business strategy and results and could cause the actual results, performance or achievements of Siemens worldwide to be materially different from any future results, performance or achievements that may be expressed or implied by such forward-looking statements. For us, particular uncertainties arise, among others, from changes in general economic and business conditions, changes in currency exchange rates and interest rates, introduction of competing products or technologies by other companies, lack of acceptance of new products or services by customers targeted by Siemens worldwide, changes in business strategy and various other factors. More detailed information about certain of these factors is contained in Siemens’ filings with the SEC, which are available on the Siemens website, www.siemens.com and on the SEC’s website, www.sec.gov. Should one or more of these risks or uncertainties materialize, or should underlying assumptions prove incorrect, actual results may vary materially from those described in the relevant forward-looking statement as anticipated, believed, estimated, expected, intended, planned or projected. Siemens does not intend or assume any obligation to update or revise these forward-looking statements in light of developments which differ from those anticipated.

Trademarks mentioned in this document are the property of Siemens AG, it's affiliates or their respective owners.