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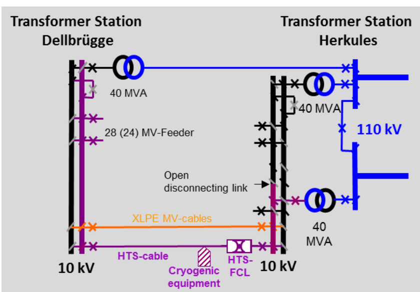
Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

Advanced Superconducting 10 kV System in the City Center of Essen, Germany



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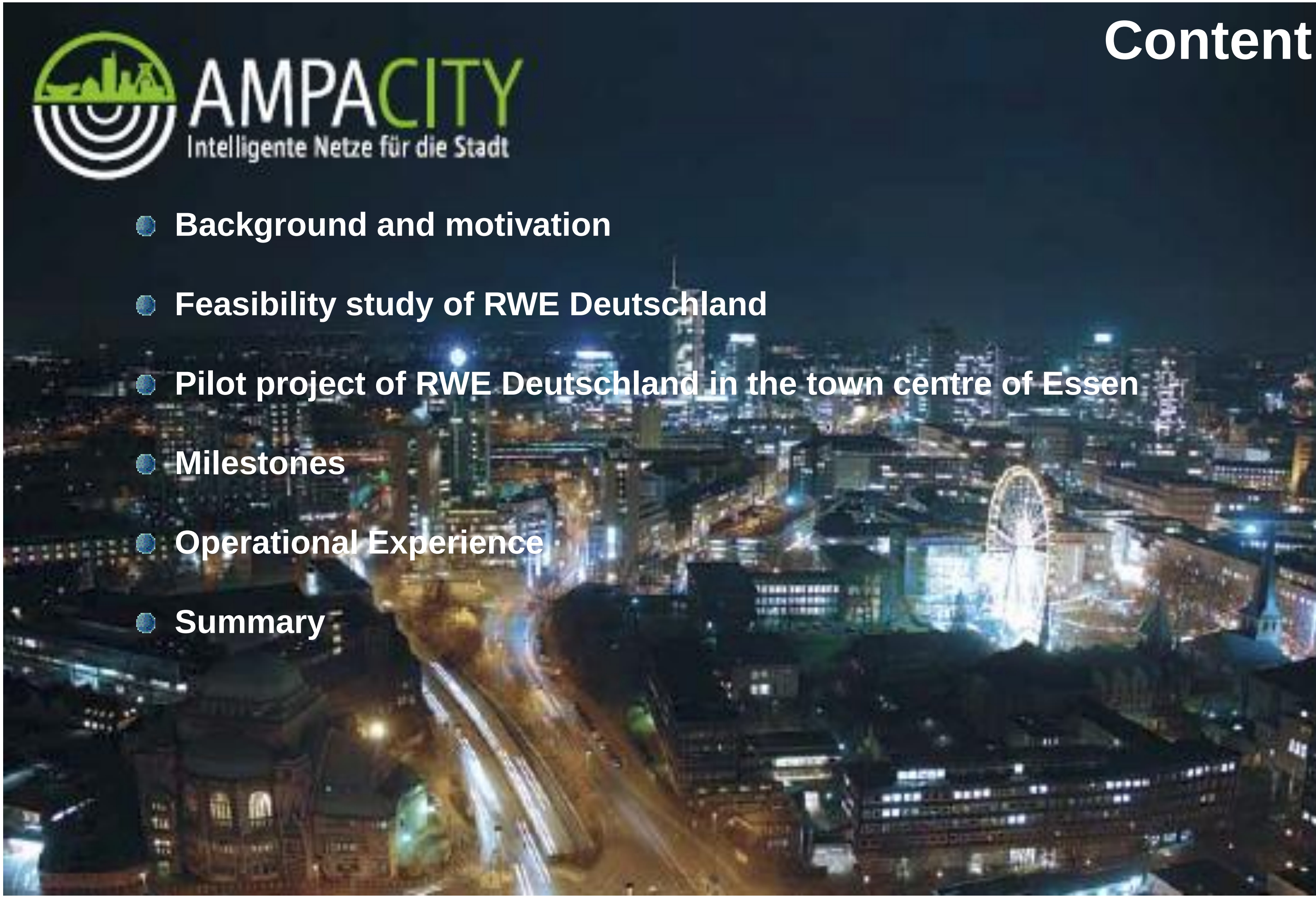
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Intelligente Netze für die Stadt
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Invited presentation 1A-LS-O1.1 given at EUCAS 2015; Lyon, France, September 6 – 10, 2015. Not submitted to *IEEE Trans. Appl. Supercond.*

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Background and Motivation

<u>Today:</u> high voltage levels for high energy densities in conurbations

> **"classical technologies" in large city grids**

- Overlaid high voltage grid
- Transformer stations high voltage/medium voltage
- Medium and low voltage grids for the further distribution of energy

> **Conventional cables and inner-city transformer stations …**

- show only low potentials for technical and econo-mical optimization because they only have restricted possibilities for new grid concepts
- claim lots of space due to the high voltage level
- have relative high losses

Advantages of supercondivity
- reduced space requirements for stations and cable routes
- less efforts for installation
- no electromagnetic impact
- dropping of transformer stations HV/MV
- options for new grid structures

→ **„double garage instead of sports hall"**

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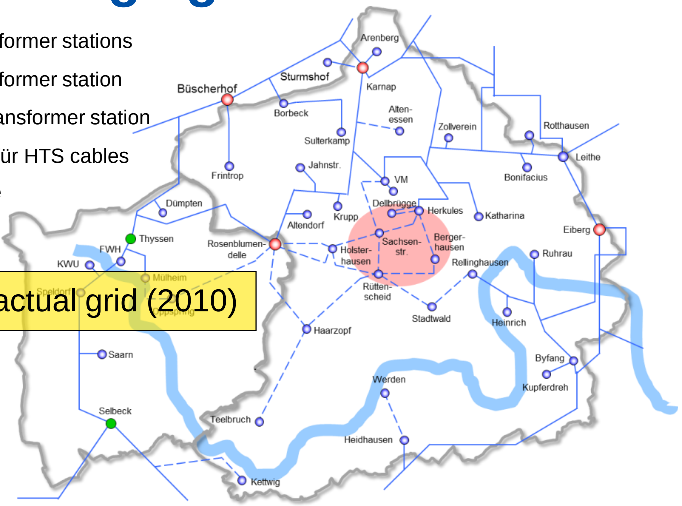
Background and Motivation

High voltage grids in the cities Essen and Mülheim

380 kV transformer stations
220 kV transformer station
110/10 kV transformer station
Target area für HTS cables
110 kV cable
110 kV OHL



feeding points in the 10 kV HTS grid
380 kV transformer stations
220 kV transformer stations
110/10 kV transformer station
10 kV load-centre substation
10 kV HTS cable
110 kV cable
110 kV OHL

City center ring with ***superconducting*** MV cables?

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Feasibility Study of RWE Deutschland

Preliminary to a field test of a longer HTS-cable a feasibility study was done

> **Client**
- RWE Deutschland AG

> **Overall control**
- Karlsruhe Institute of Technology
  Institute for Technical Physics

> **Calculations**
- Leibniz University Hannover
  Institute for Energy Supply and High Voltage

> **Technology**
- Nexans

Superconducting MV Cables for Power Supply in Urban Areas

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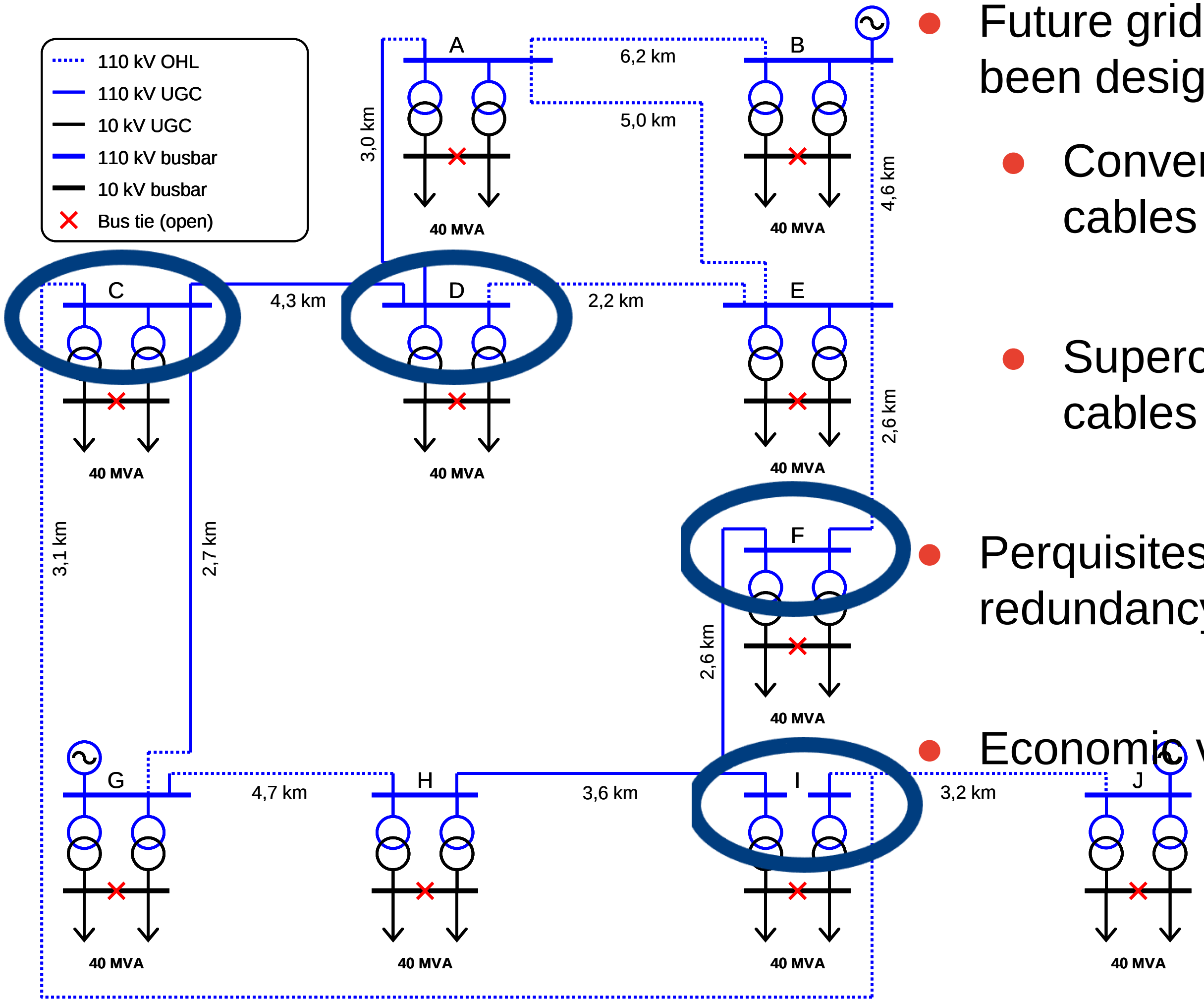
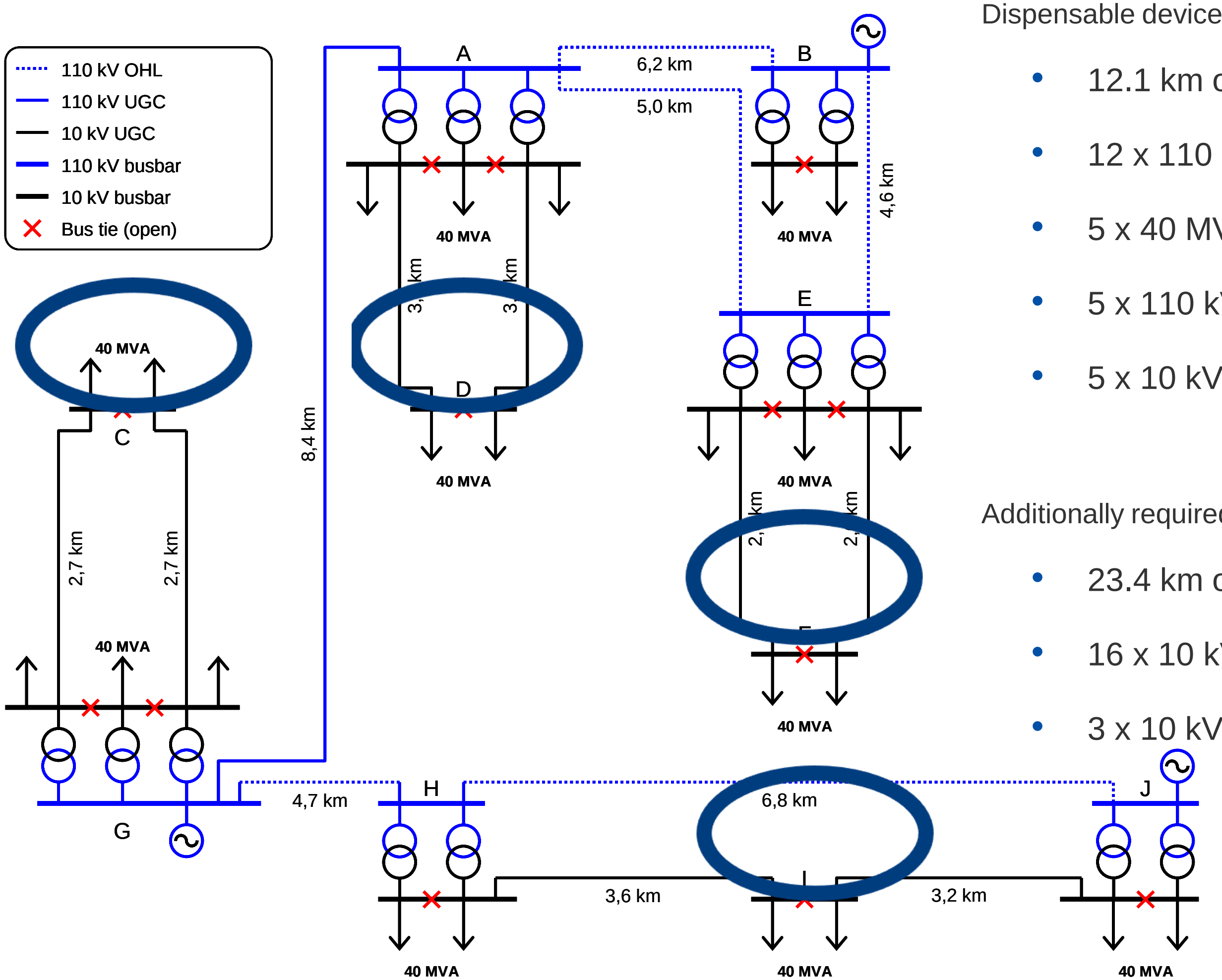
Grid Layout with MV HTS Cables



- Future grid structure has been designed based on
  - Conventional 110 kV cables
  - Superconducting 10 kV cables
- Perquisites: same redundancy (n-1)
- Economic viability compared

Grid Layout with MV HTS Cables



Dispensable devices for new grid concept

- 12.1 km of 110 kV cable systems
- 12 x 110 kV cable switchgear
- 5 x 40 MVA, 110/10 kV transformers
- 5 x 110 kV transformer switchgear
- 5 x 10 kV transformer switchgear

Additionally required devices for new grid concept

- 23.4 km of 10 kV HTS cable system
- 16 x 10 kV cable switchgear
- 3 x 10 kV bus ties

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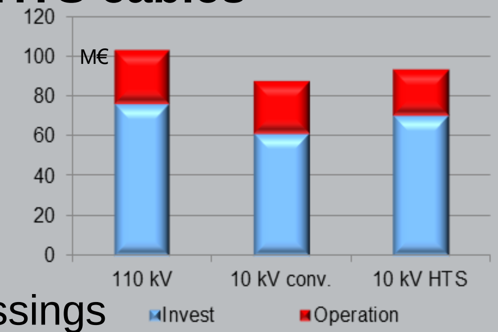
Feasibility Study - Summary

The HTS cable technology offers technical, operational, economical and processual advantages

> **Increased power density through application of HTS cables**

- Avoiding higher voltage levels for power distribution



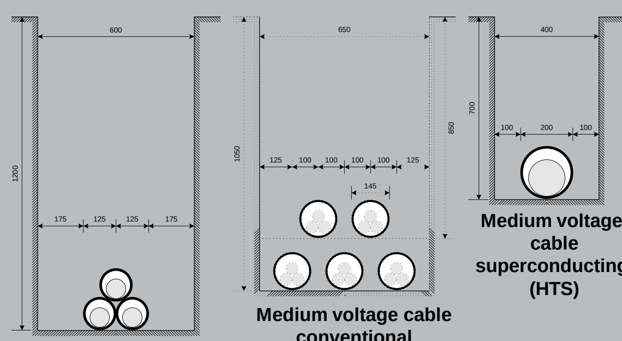
> **Negligible thermal impact on the environment**

- No drying out of soil, no thermal backfill required
- No maximum laying depth, no bottlenecks at cable crossings

> **No outer magnetic field during normal operation**

> **Reduced space for substations and for cable installation**

- Simplified cable installation, less civil works
- Space-savings in urban areas



> **Increased operating safety due to fault current limitation**

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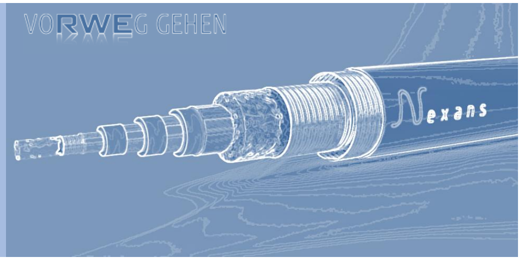
Pilot Project of RWE Deutschland

Positive results of the study are the basis for testing an HTS system in the inner city of Essen

Start of the project:	September 2011
Installation of the cable:	3rd/4th quart of 2013
Inauguration:	Spring of 2014
Total duration of project:	4.5 years



- Proof of the technical suitability of superconducting technologies (cable and fault current limiter) in distribution grids
- Evaluation of the investment for a 10 kV cable in combination with a superconducting fault current limiter as an alternative to a 110 kV cable system
- Demonstration of technical advantages of the running system over a period of two years
- Estimation of further potential applications of the HTS cable technology
- Due to the innovation character, the project AmpaCity is funded by the German Ministry of Economics

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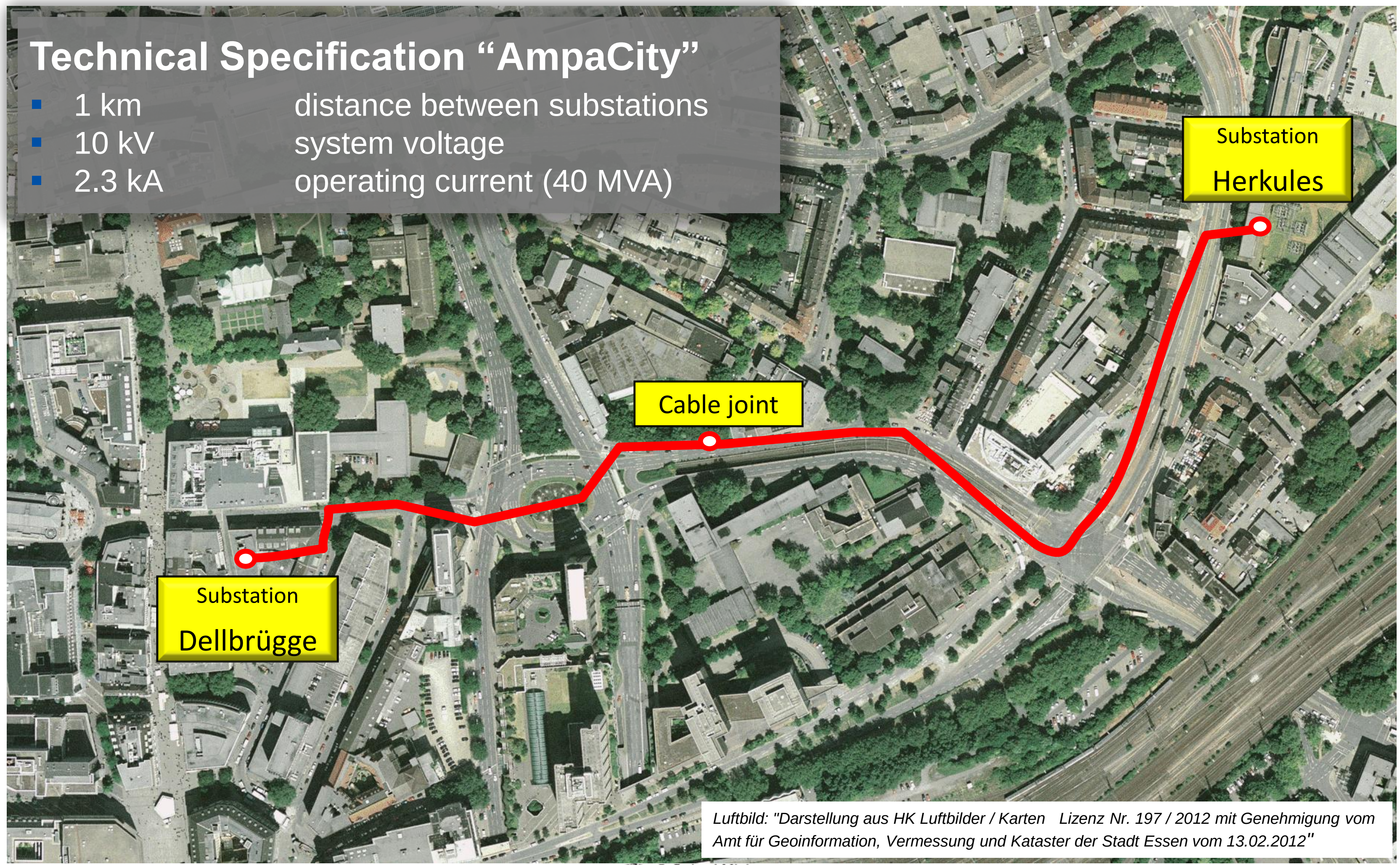
Pilot Project of RWE Deutschland

Technical Specification "AmpaCity"

- 1 km distance between substations
- 10 kV system voltage
- 2.3 kA operating current (40 MVA)



Luftbild: "Darstellung aus HK Luftbilder / Karten Lizenz Nr. 197 / 2012 mit Genehmigung vom Amt für Geoinformation, Vermessung und Kataster der Stadt Essen vom 13.02.2012"

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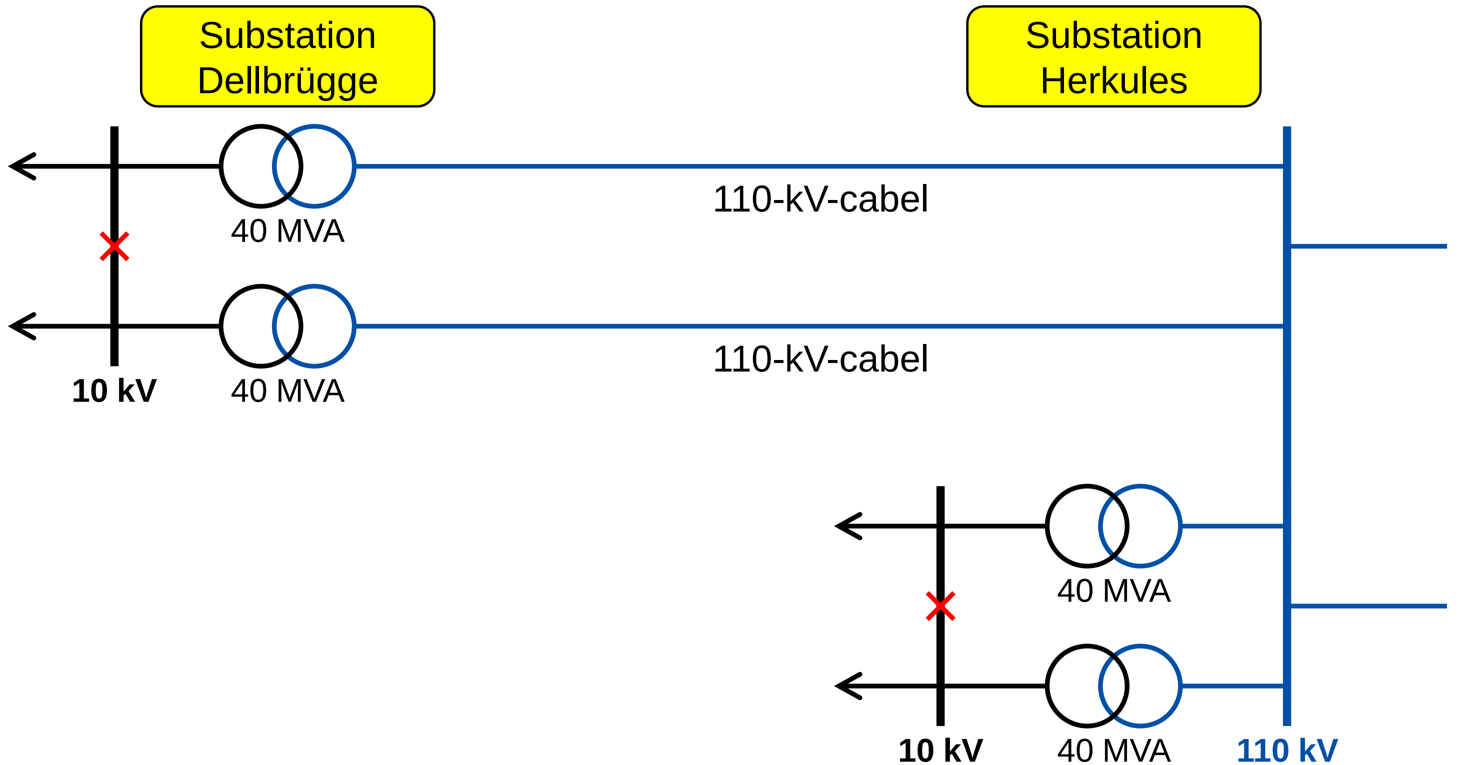
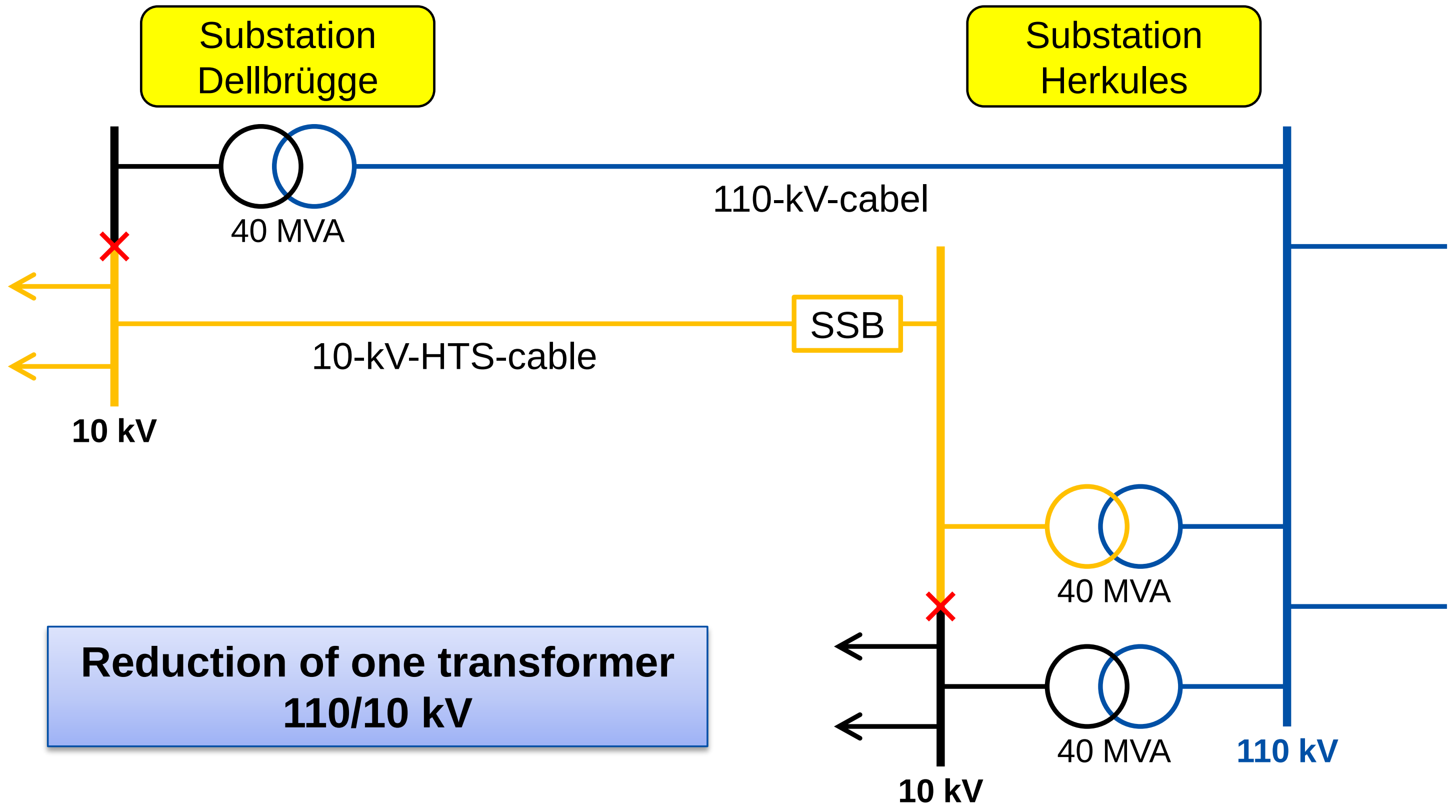
AmpaCity – One Line Diagram Initial Situation



AmpaCity – One Line Diagram Current Situation



Reduction of one transformer 110/10 kV

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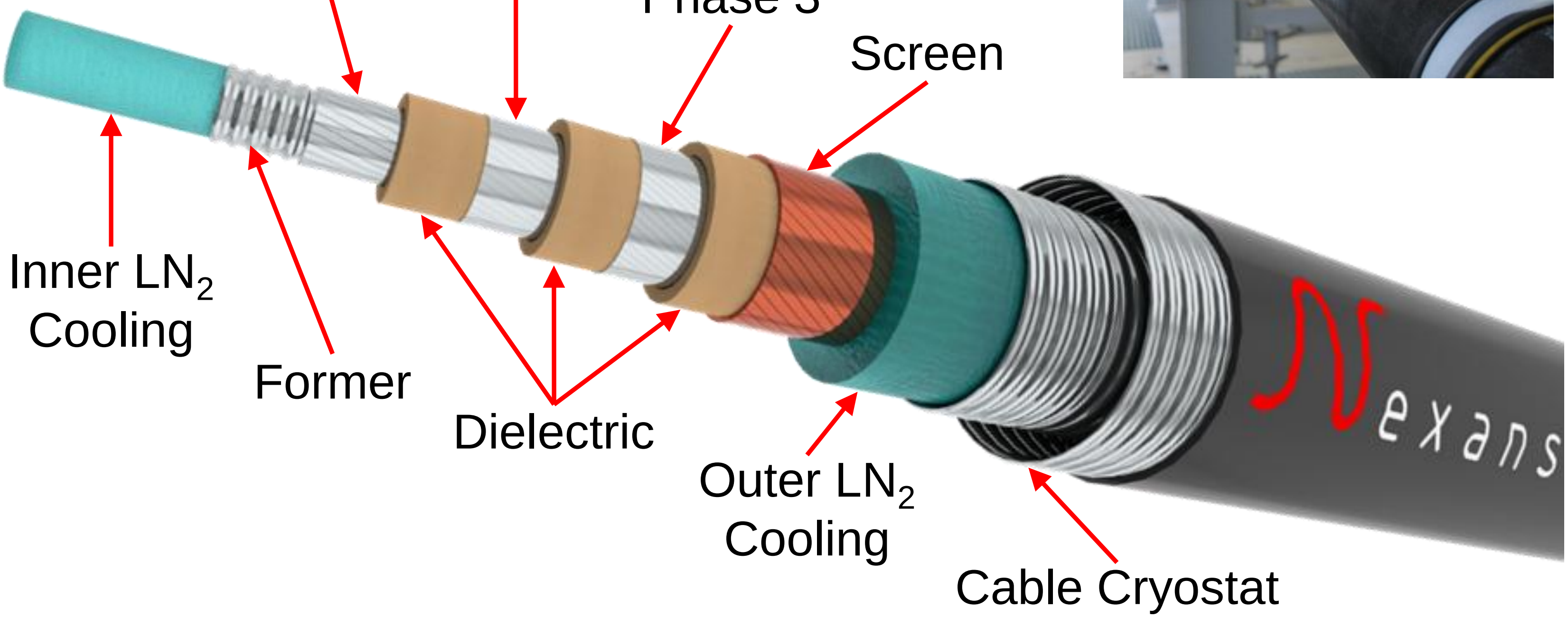
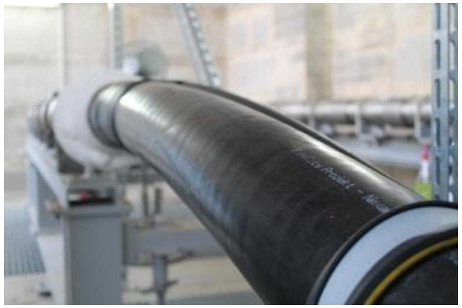
The components of AmpaCity

HTS-Cable with concentric design





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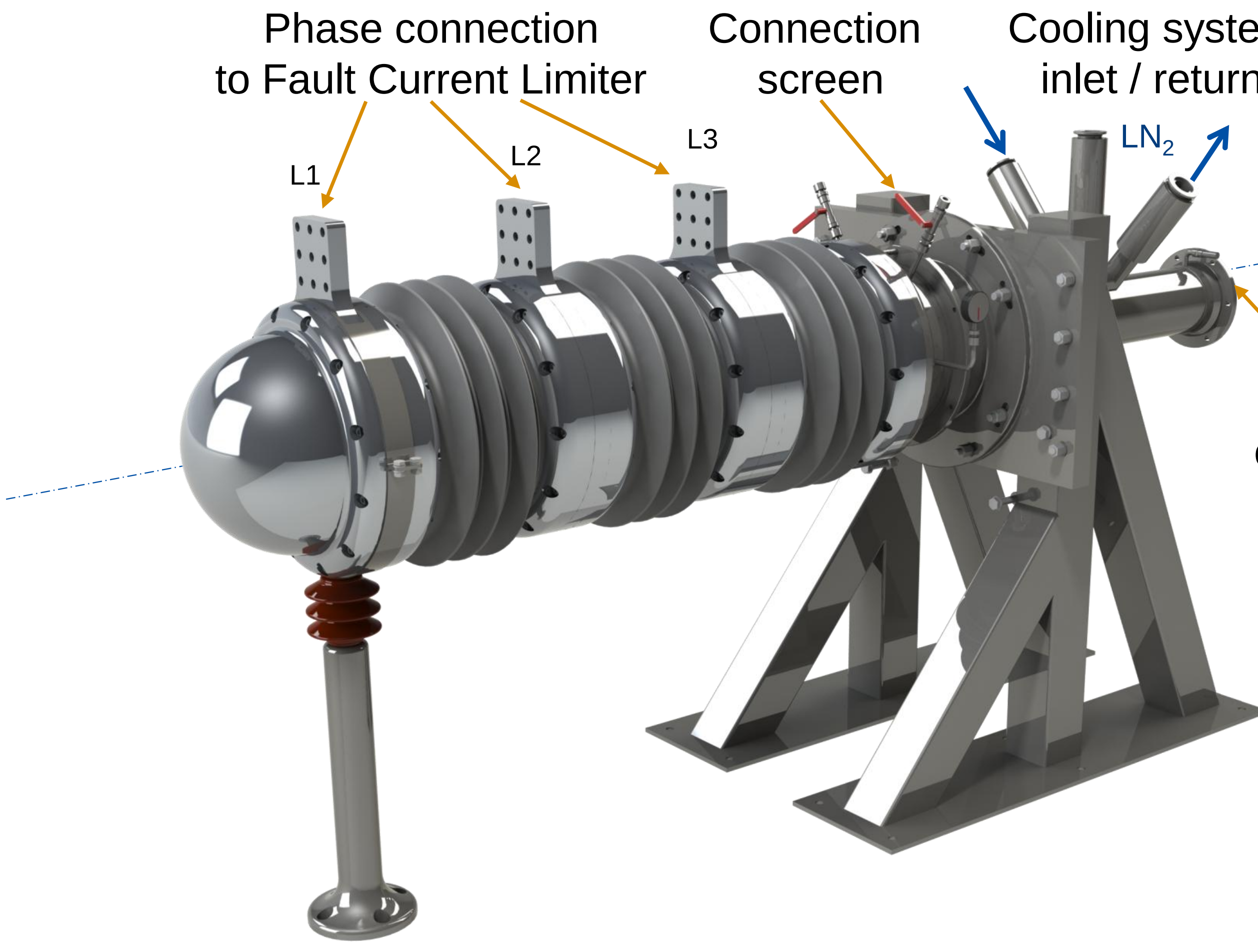
The components of AmpaCity

Termination



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The components of AmpaCity

Joint

> **Connection of two sections midway between the two substations**

- Due to transport reasons it is neccessary to divide the cable length of one kilometer in two sections
- Electrical connection coupling → cable core
- Thermal connection coupling → cryostat

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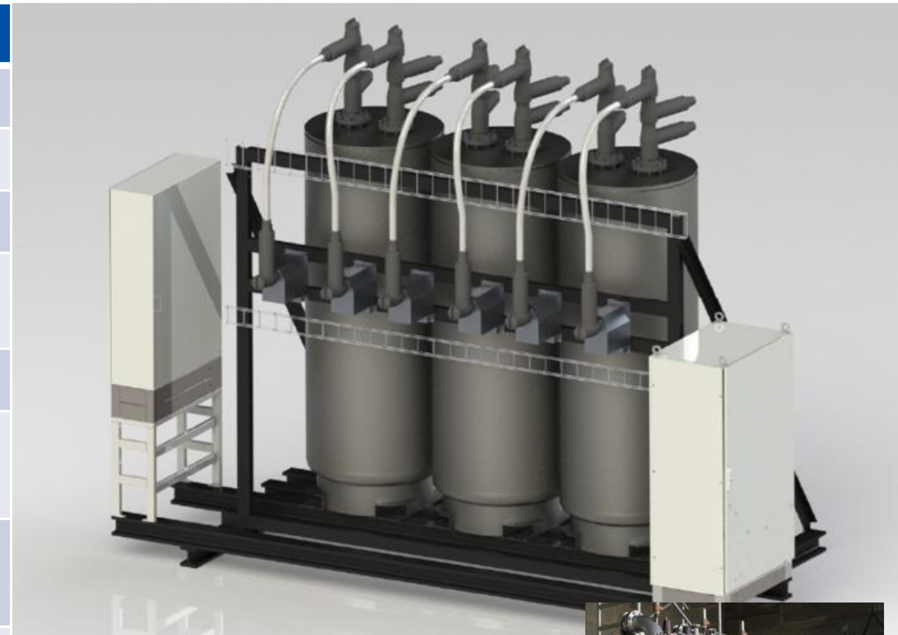
The components of AmpaCity

Superconducting fault current limiter

Parameter	Value
Nominal power	40 MVA
Nominal voltage	10 kV
Operating current	2.3 kA
Rated lightning impulse withstand voltage	75 kV
Rated AC withstand voltage	28 kV
Prospective unlimited peak current	50 kA
Prospective unlimited symmetric current	20 kA
Limited peak current	< 13 kA
Limited symmetric current	< 5 kA
Limitation time	100 ms
Recovery time	< 10 min



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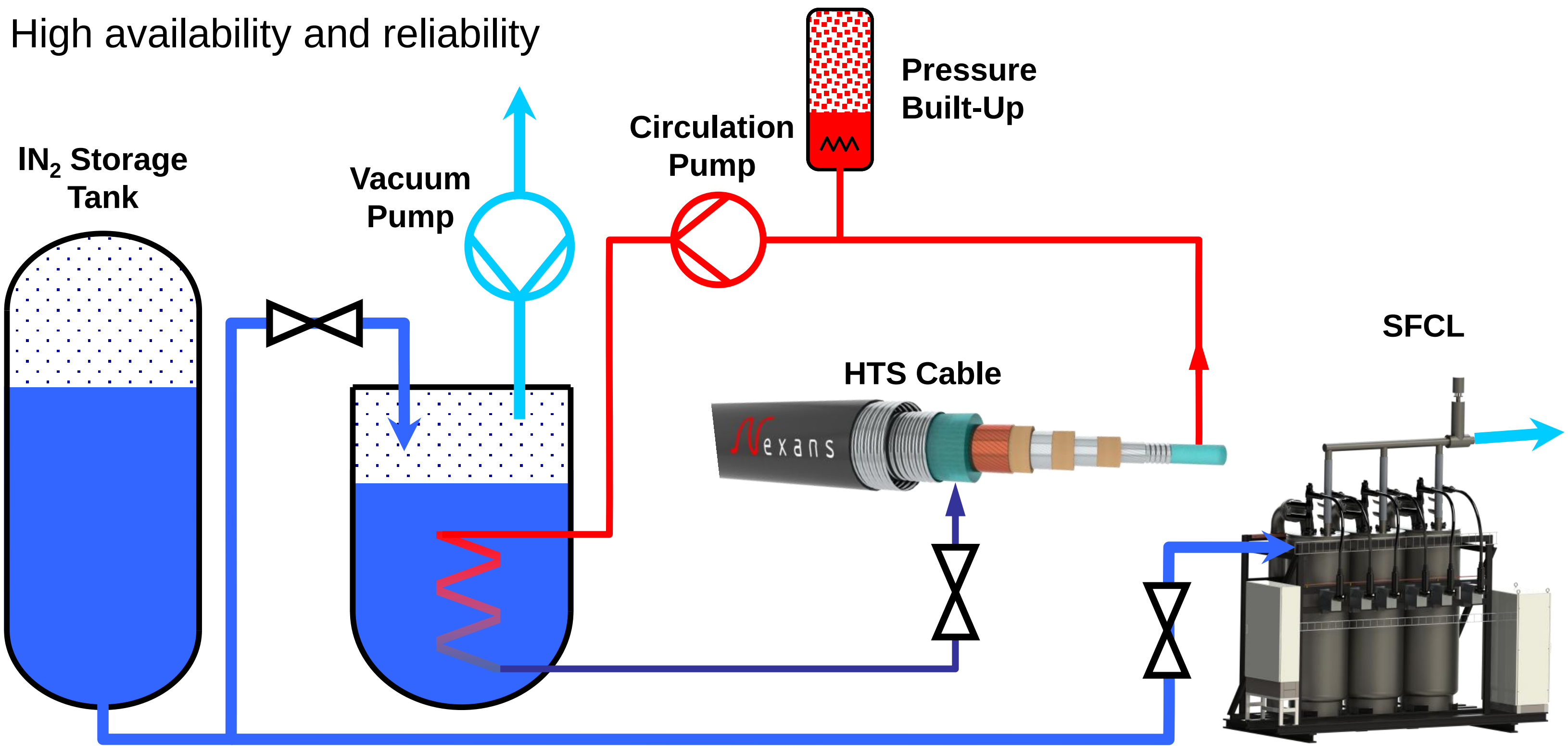
Cooling System

- 4 kW cold power @ 67 K
- Subcooled liquid nitrogen
- Closed circulation of nitrogen in the cable
- High availability and reliability



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Pilot Project of RWE Deutschland

Milestones

- ✓ Submission of the grant application to the German Federal Ministry of Economics and Technology (BMWi) at April 19th,2011 and July 15th, 2011
- ✓ Receipt of the grant decision of the BMWi at September 5th, 2011
- ✓ Production of the prototype cable in the second half of 2012
- ✓ Completion of the type test in the first quarter of 2013
- ✓ Starting production of the cable system at the end of first quarter 2013
- ✓ Turning of the first sod in Essen April 9th, 2013
- ✓ Installation of the complete system in the third and fourth quarter of 2013
- ✓ On-site test and first commissioning trial in December 2013
- ✓ Putting into operation on April 30th 2014
- Testing from 2014 to 2016
- Evaluation of the results and commitment of further steps in the beginning of the year 2016

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The components of AmpaCity

Test set-up for type test (Nexans, Hannover)

> **Qualification test of the system previous to the installation in Essen**

- Test set-up: two cable sections (total 25 m), two terminations, one connection coupling
- Tests according to German standard DIN VDE 0276 and relevant IEC-drafts (IEC: international Electrotechnical Commission)
- Succesfully completed March 2013

  → production of the components started

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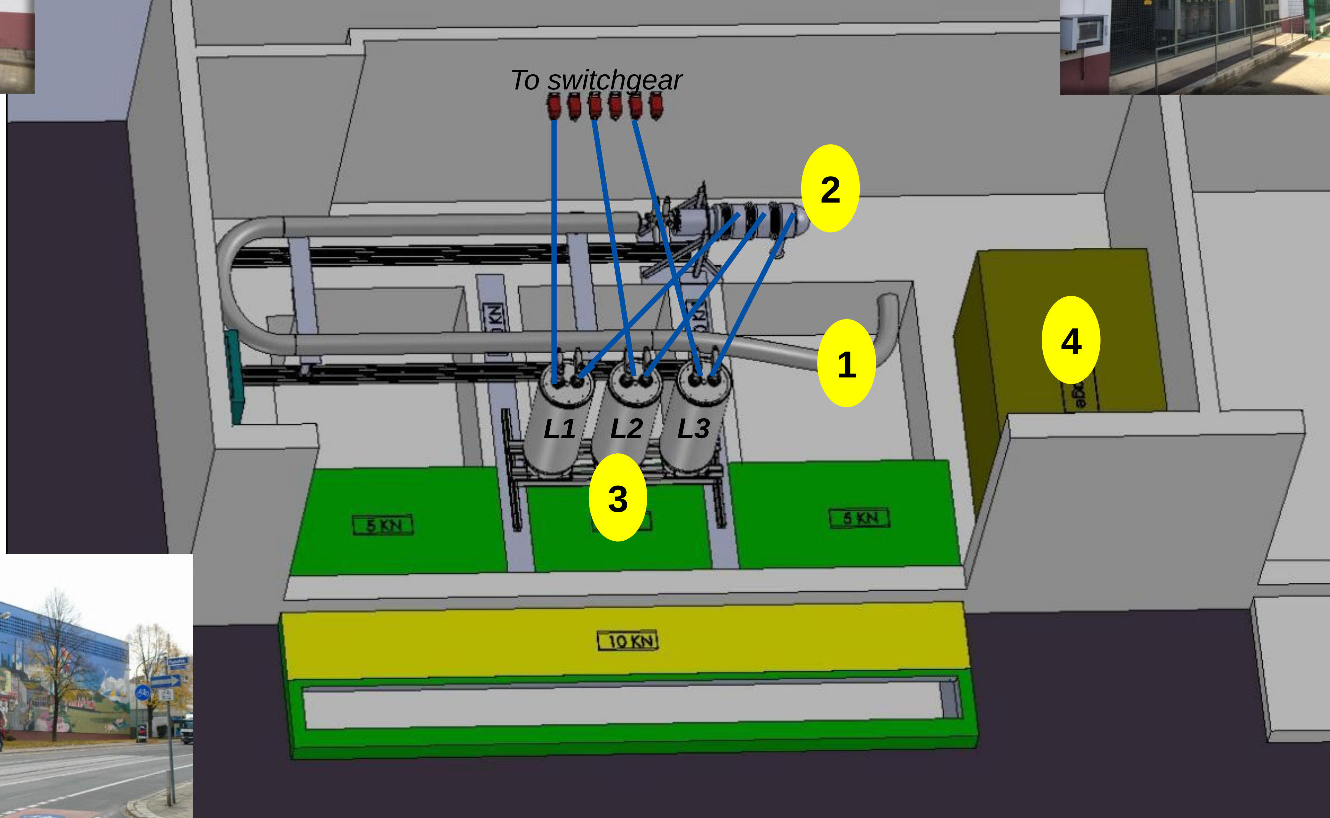
The components of AmpaCity

Components layout on site

Transformer box in the substation „Herkules“



1 Cable

2 Termination

3 Fault current limiter

4 cooling system

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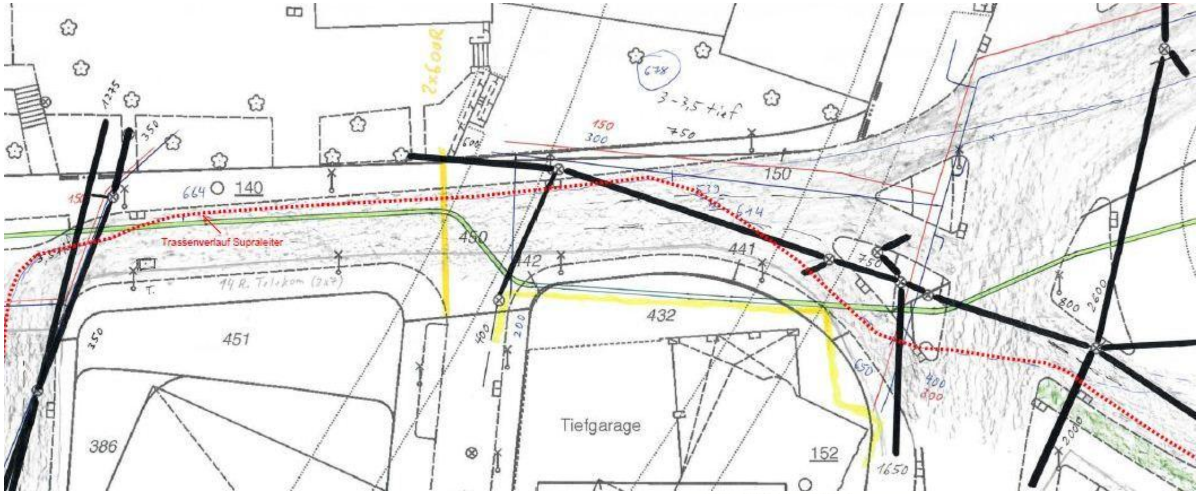
Civil engeneering

Routing in the center of Essen

> **Elaborate preparations were neccessary**

- Very high density of different supply and disposal lines in the inner-city area (electricity, gas, water, district heating, canalisation, telecommunication, …) requires detailled preliminary planning
- Agreements with different companies and authorities
- „Blueprints and reality“→ a great number of surprises (dead-end conductions, contaminated soils, heaps of ruins, changes of location and depth, …)



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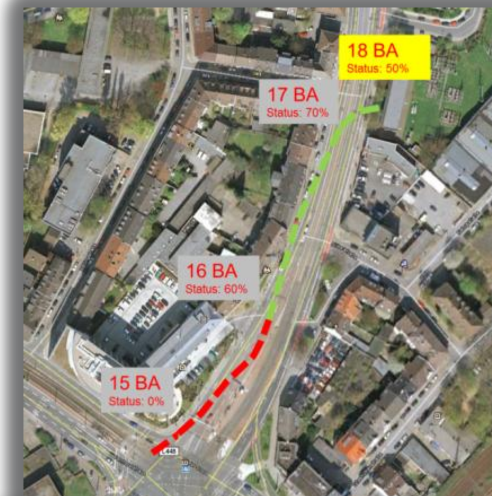
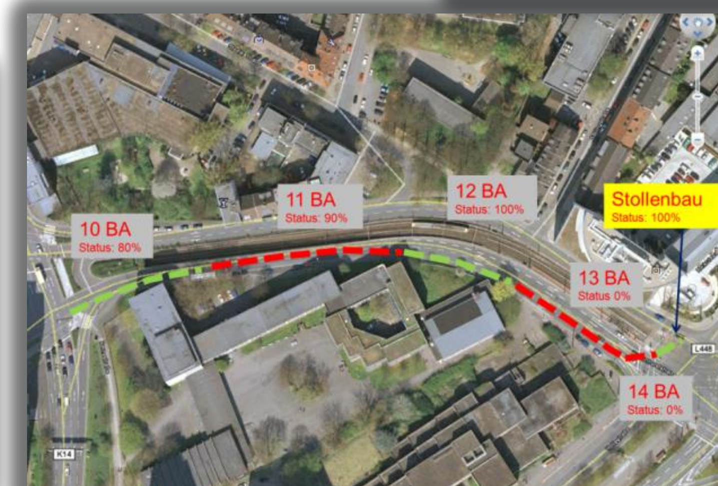
Civil engeneering

… an essential component for the realization of the project

> **Reduction of the expense and the negative impacts**

- Less amount of space for the HTS system
- Division into construction phases
- Laying of empty conduits for cable pulling





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Installation and pre-commissioning

Installation of the components September - November 2013

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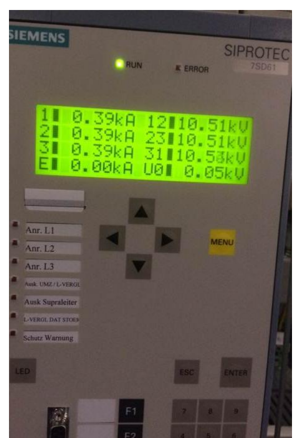
Installation and pre-commissioning

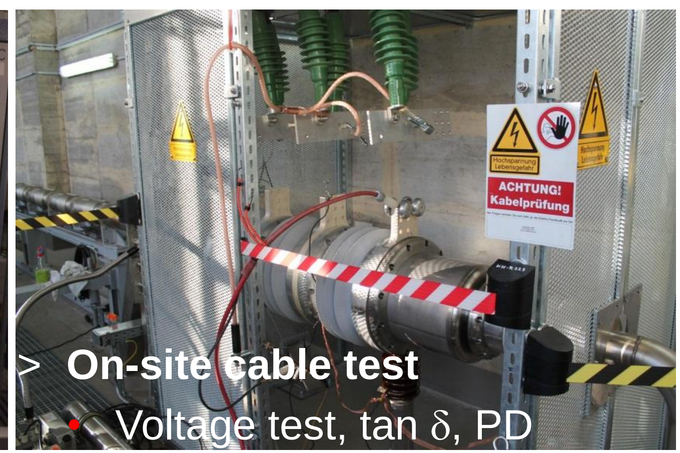
Installation of the components September - November 2013

> Refrigeration system
- Delivery, installation of the LN-tank

> Superconducting fault currrent limiter
- Installation

> Refrigeration system
- Mounting





> On-site cable test
- Voltage test, tan δ, PD

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Commissioning Test

> Standard cable test with VLF equipment

> PD measurement
(20 kV @ 0,1 Hz)

> Dielectric loss factor measurement
(10 kV, 15 kV, 20 kV @ 0,1 Hz)

> AC withstand voltage test
(30 kV @ 0,1 Hz for 1 h)

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Commissioning

Official inauguration on 30th April, 2014

World premiere in Essen:
RWE integrates for the first time a superconducting cable system in existing city grid

- **Prime Minister Hannelore Kraft: high significance for „energy country NRW“**

From left to right: Dr. Joachim Schneider, CTO RWE Deutschland AG, Dr. Arndt Neuhaus, CEO RWE Deutschland AG, Peter Terium, CEO RWE AG, Reinhard Paß, Lord Mayor of the City of Essen, Dr. Johannes Georg Bednorz, Nobel laureate 1987, Dr. Hans-Christoph Wirth, German Federal Ministry for Economic Affairs and Energy, Hannelore Kraft, Prime Minister of the German federal state North Rhine-Westphalia, Christof Barklage, CEO Nexans Deutschland GmbH, Prof. h.c. Dr. Joachim Knebel, area manager Karlsruhe Institute for Technology

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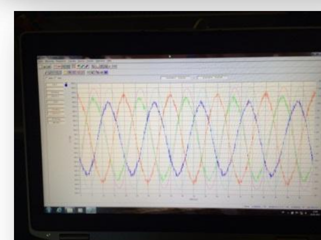
Operation - „lessons learned“

Operation without problems since commissioning , however some optimisations during operation

> **Balancing the earth capacitance**
- Compensation of the unsymmetric earth capacitances of the AmpaCity cable by installation of capacitors

> **Optimisation cooling system**
- Modification of the vacuum pumps after freezing of humid air; some smaller optimisations

> **Optimisation system control**
- Increase of the response time after automatic reclosing for non-disruptive operation



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Operation - some data

> **since starting the operation 16 months ago …**
- About 60 Million kWh had been transmitted with the AmpaCity cable
- Roughly 100 groups with in total more than 2,000 interested participants from Europe and various parts of the world (e.g. U.S., China, Australia, Korea) visited the HTS installation in the station Herkules,

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Operation - short circuit tests

Short circuit and ground fault tests

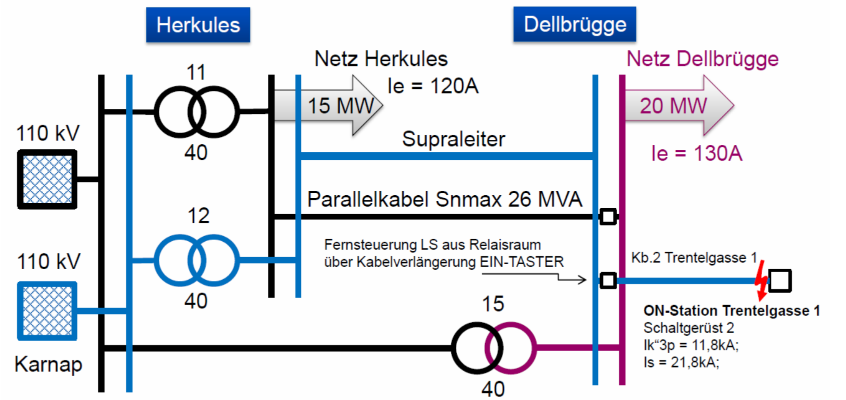
- In order to study the short-circuit behavior of the high-temperature superconductor, on June 23rd, 2015 the HTS system was subject to various short circuit and ground fault scenarios to study the performance under these conditions.

- For the experiments, special circuits were constructed to eliminate negative influence of customers or other networks.

- To limit the ground fault current, the transformer 15 has been turned on in the station Dellbrügge for supplying the subnet Dellbrügge.

Short circuit tests AmpaCity

- Special circuit



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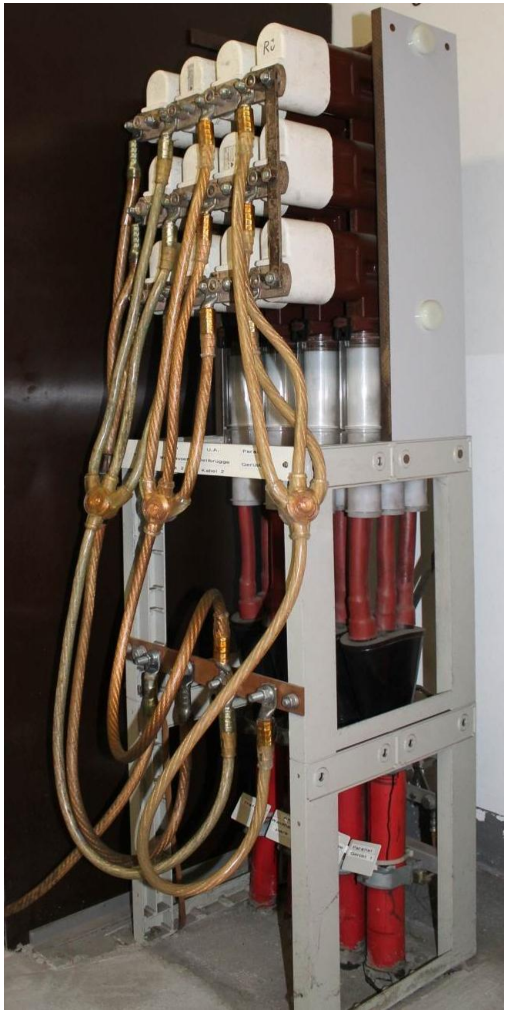
Operation - short circuit tests

Short circuit and ground fault tests

> **The following tests were carried out:**

- Short circuit test, three poles, without earth contact – two tests
- Short circuit test bipolar, without earth contact – one test1
- Ground fault test single-pole, duration 5 min, then short grounding system
  Earth fault current < 20 A



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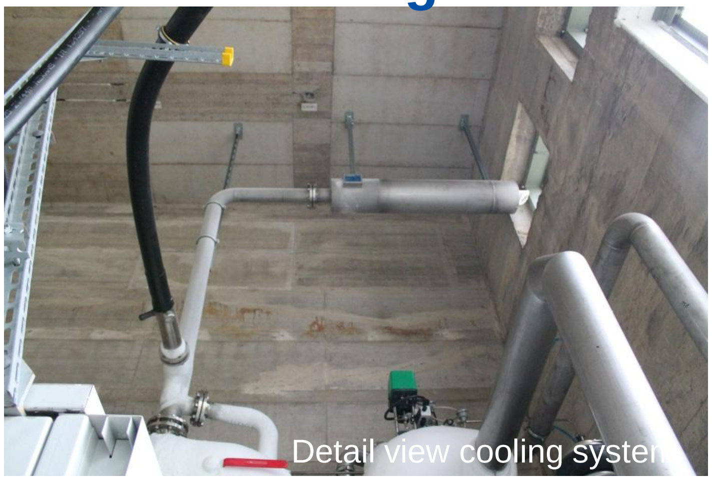
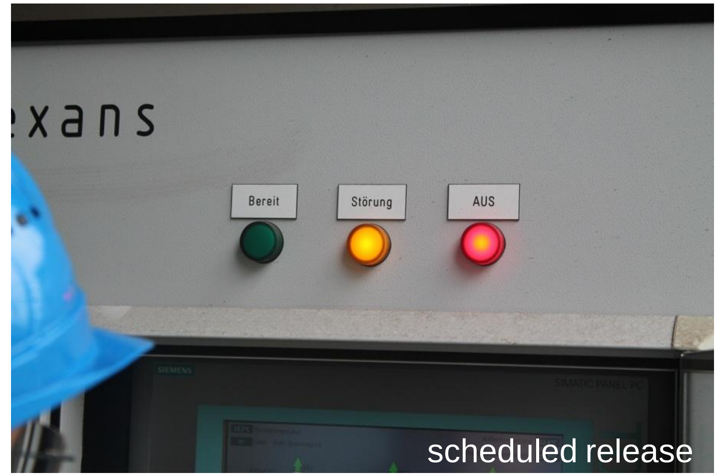
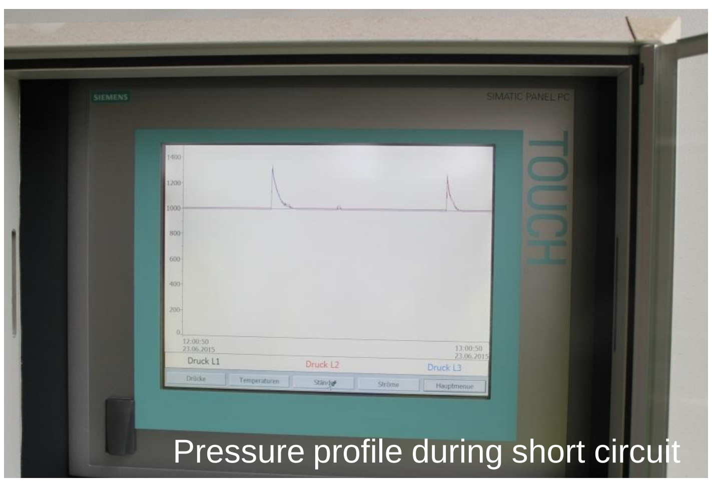
Operation - short circuit tests

Short circuit and ground fault tests

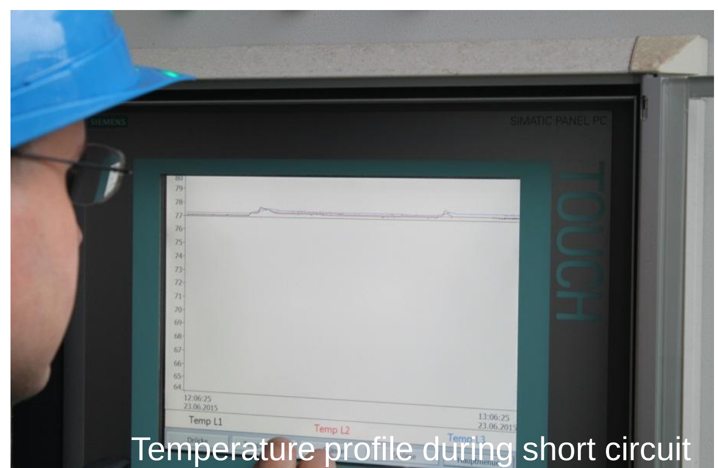

Detail view cooling system



scheduled release



Pressure profile during short circuit



Temperature profile during short circuit

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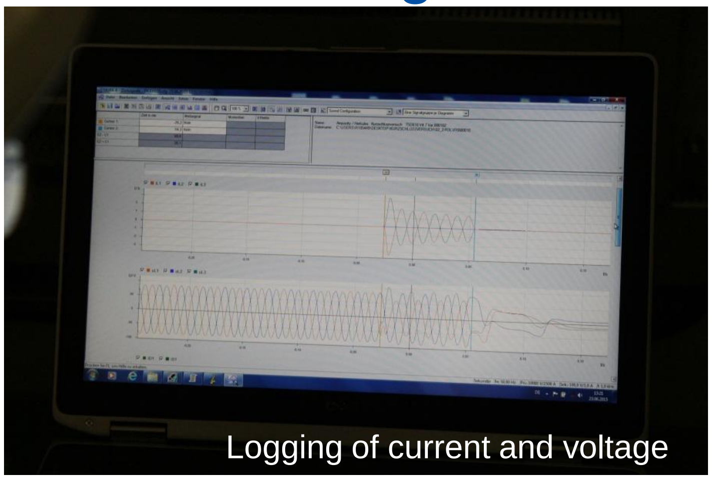
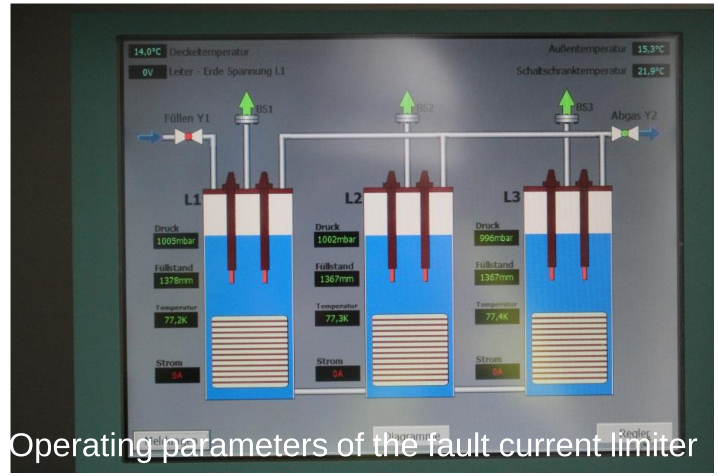
Operation - short circuit tests

Short circuit and ground fault tests


Logging of current and voltage



Operating parameters of the fault current limiter

Ready for operation after a short recovery time


Fault current limiter ready for operation again

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Operation - short circuit tests

Short circuit and ground fault tests

All tests conducted gave the expected results

The HTS system works exactly as expected including the fault current limitation

The test proves the maturity of the technology under real grid conditions

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Summary

The HTS technology has an important future potential

Feasibility study with very positive results; amongst others:

- HV/MV stations in conurbations can be dropped by using HTS sytems
- smarter grid structures and less requirement of space by extension of the grid with HTS cables

Testing the superconducting cable in practical use at RWE

- The field test in Essen is proving the maturity of HTS system under real grid conditions

Superconducting components will become more competitive to conventional technology

- increasing capacity for the production of superconducting tapes
- scaling effects for cable system production
- reduced development and engineering
- optimized cable laying

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Thank You for Your Attention

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