Nexans
ELECTRIFY THE FUTURE

Nexans is paving the way for a superconducting electric world

ARNAUD ALLAIS / JUNE 14, 2022

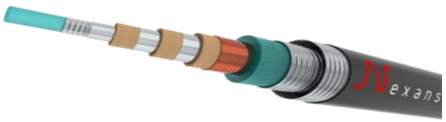
HTS 2022 Modelling

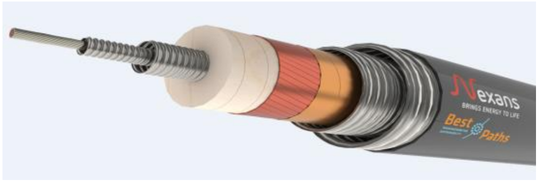
8th International Workshop on Numerical Modelling of High Temperature Superconductors
14th – 16th June 2022, Nancy, France

Content

1 HTS Solutions for Grids

1.1/ Nexans HTS solutions

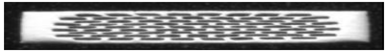
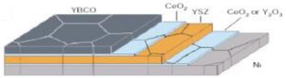
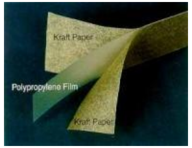




- **MV AC Cable**
  - **Inner City substation connection**
  - Industrial plant
  - Gas pressure / pipe type retrofit
- **HV AC Cable**
  - Inner city power transmission
  - OHL partial undergrounding
- **Very High Current DC Cable**
  - Degaussing applications
  - Electrolysis power feeder
  - Railway application

- **MV AC FCL**
  - HTS Cable system component
  - Stand alone application
- **MV DC FCL**
  - Railway application

1.2 / HTS cable system components

Conventionnal Cable			HTS cable	
Current conduction		Copper wire		Bismuth-based 1G tape
	or		*or*	
		Aluminium wire		Yttrium-based 2G tape
Electrical insulation		Cross-linked polyethylene (XLPE)		PolyPropylene Laminated Paper (PPLP)

1.2 / HTS cable system components

Conventionnal Cable

HTS cable

Connections

Joints **Terminations**

Joints

Terminations

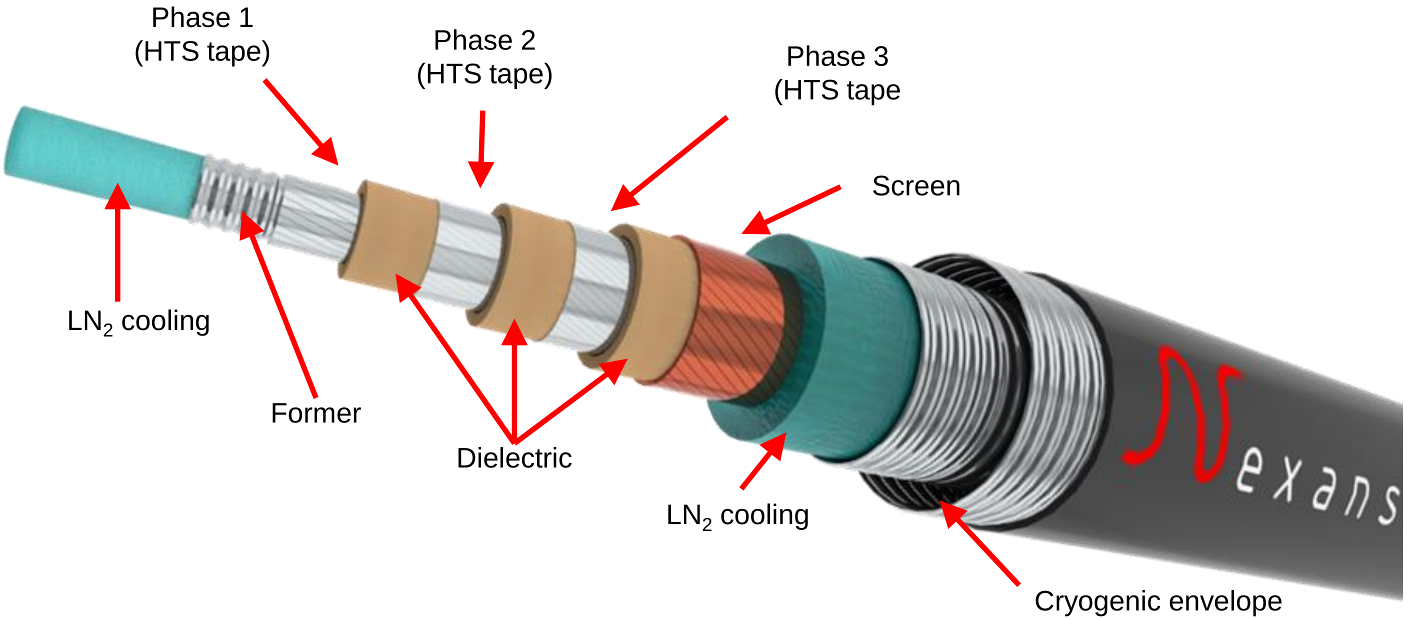
Thermal insulation

Cryogenic envelope

1. Corrugated inner tube
2. Low-loss spacer
3. Vacuum space ($<10^{-5}$ mbar)
4. Multilayer superinsulation
5. Corrugated outer tube
6. Polyethylene jacket

Liquid nitrogen cooling system

1.1 / 3-phase cable design for MVAC applications



1.2 / Cable phase design for HVAC applications

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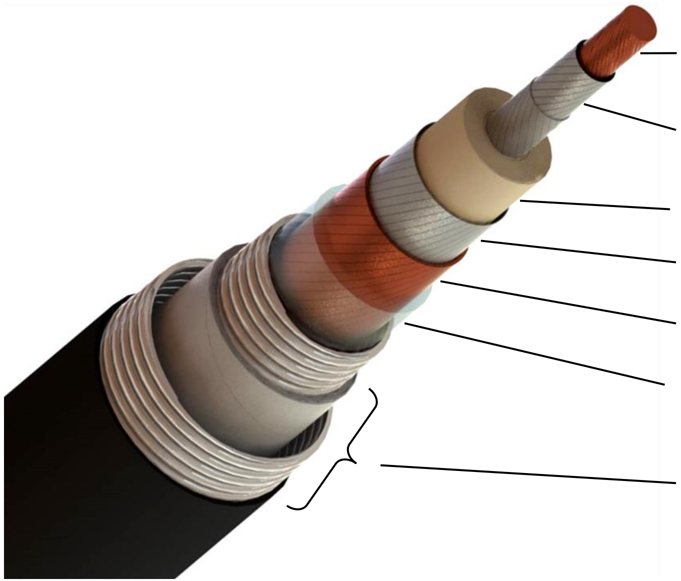
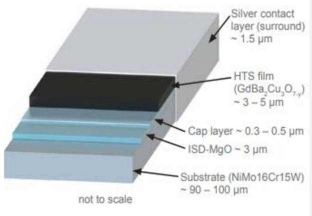
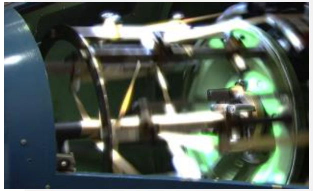


1.2 | HTS cables Technologies Readiness Levels



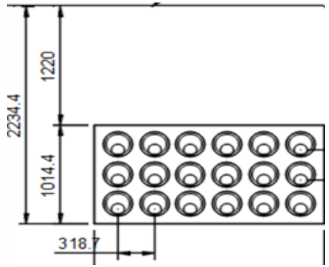


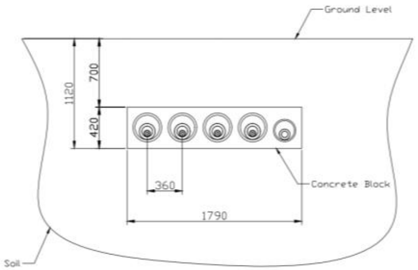
ALL BRICKS ARE INDUSTRIAL

- Production of superconducting tapes (thin film coating of metallic tapes) are strongly pushed by demands for fusion and land superconducting cables.
- All processes for cable core manufacturing are the same as for HV submarine conventional cables (tape stranding, paper or PPLP dielectric lapping – no limitation in length).
- Flexible cryostats are widely used for spatial (liquid oxygen and hydrogen) and energy markets (LNG, hydrogen). They have been manufactured for more than 40 years and can be continuously produced around the cable core.
- Cooling stations above 100 kW@ liquid nitrogen temperature are produced in series and currently installed on decks of LNG tankers

1.2 | HTS cable benefits – Compactity / Neutrality

NO ELECTROMAGNETIC FIELD



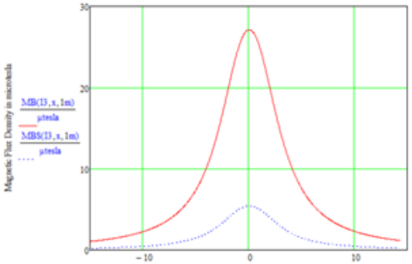


Without shielding

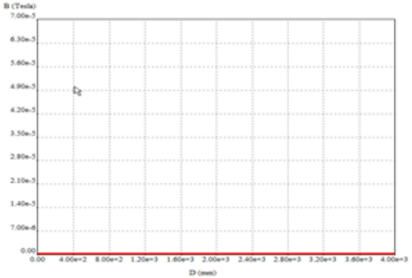
MB(I3, 1·m, 1·m) = 26.871·μtesla

With shielding around duct

MBS(I3, 1·m, 1·m) = 7.677·μtesla



138 kV resistive cables



138 kV HTS cables

B_{max} = 0.0017 μT

1.3 | HTS Resistive FCL - Unique Benefits

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#01

INVISIBLE TO THE GRID

#02

REDUCE SHORT CIRCUIT CURRENTS

– lower rating equipment

#03

ENABLE GRID COUPLING

#04

ALLOW OR SIMPLIFY DISTRIBUTED GENERATION

#05

IMPROVE SAFETY

#06

COMPATIBLE WITH UNMANNED OPERATIONS

1.3 | HTS Resistive FCL - Characteristics

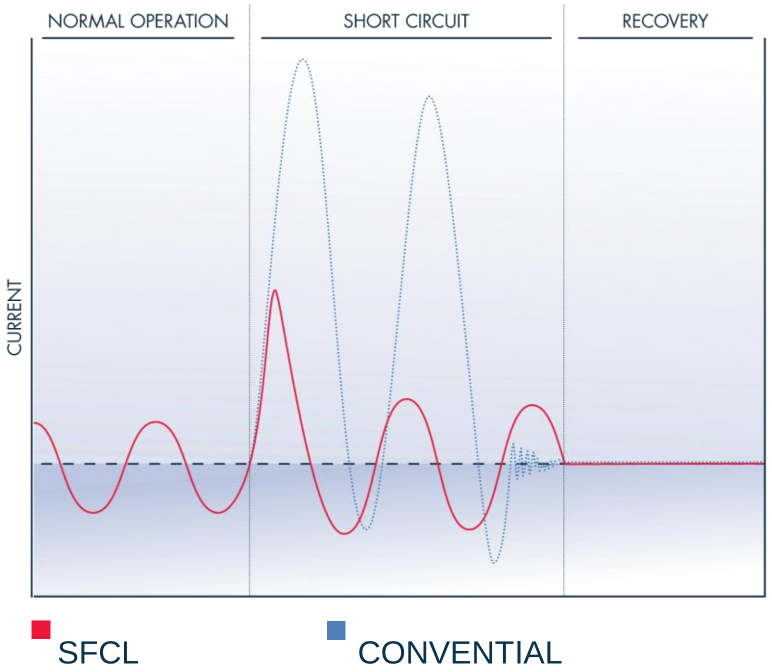
FAST
- Reacts in <2msec
- Ensure voltage stability during fault

AUTOMATIC
- No external trigger necessary
- Self-recovery

WEAR-FREE
- Service only required to maintain cooling

UNMANNED OPERATION:
- No spare parts on site
- No action of operators required

PROTECTION COORDINATION:
- Does not impact existing protection



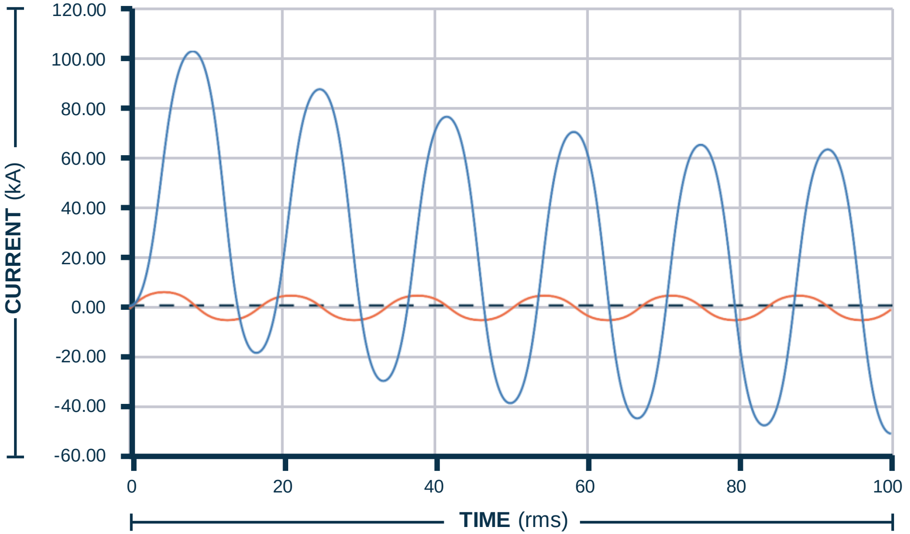
1.3 | HTS Resitive FCL - Assets Life Extension

DRASTIC LIMITATION OF HIGH FAULT CURRENTS DAMAGE TO:

- Breakers
- Grounding equipment
- Transformers
- Cables

BENEFITS

- Reduces or eliminates the need to upgrade circuit breakers or add series reactors
- Eliminates need to reinforce buswork
- Prevents equipment damage to ancillary equipment and the follow on replacement



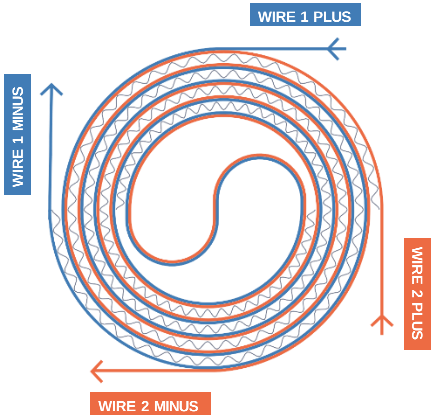
Prospective current and limited current for pphase A of the 1200A

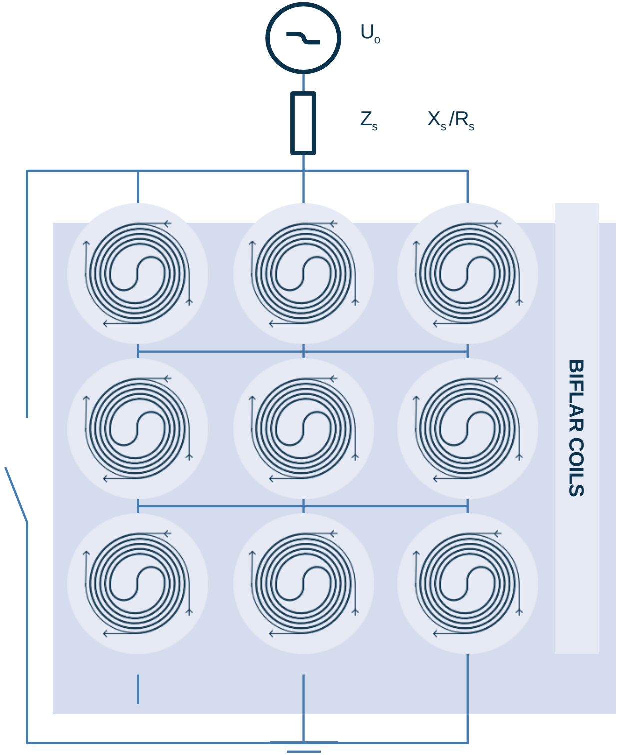
Unit: Assumptions: fault current 40 kA (rms), X/R =16

1.3 | HTS Resistive FCL ranges

- Medium voltage fault-current limiters (6 kV - 36 kV)
- AC (16.67 Hz - 60 Hz) or DC
- Currents in the range of a few hundred A to 5kA
- Different cooling options
- Limited current adjustable to customers' needs
- Operation monitoring
- Installation, commissioning and service

1.3 | HTS Resistive FCL - Design basics





- The sFCL uses is made up of an array of standard “FCL Coils”
- Coils are arranged in a array
- # of Columns in parallel selected to achieve desired current rating
- # of Rows in series selected to achieve desired limiting resistance

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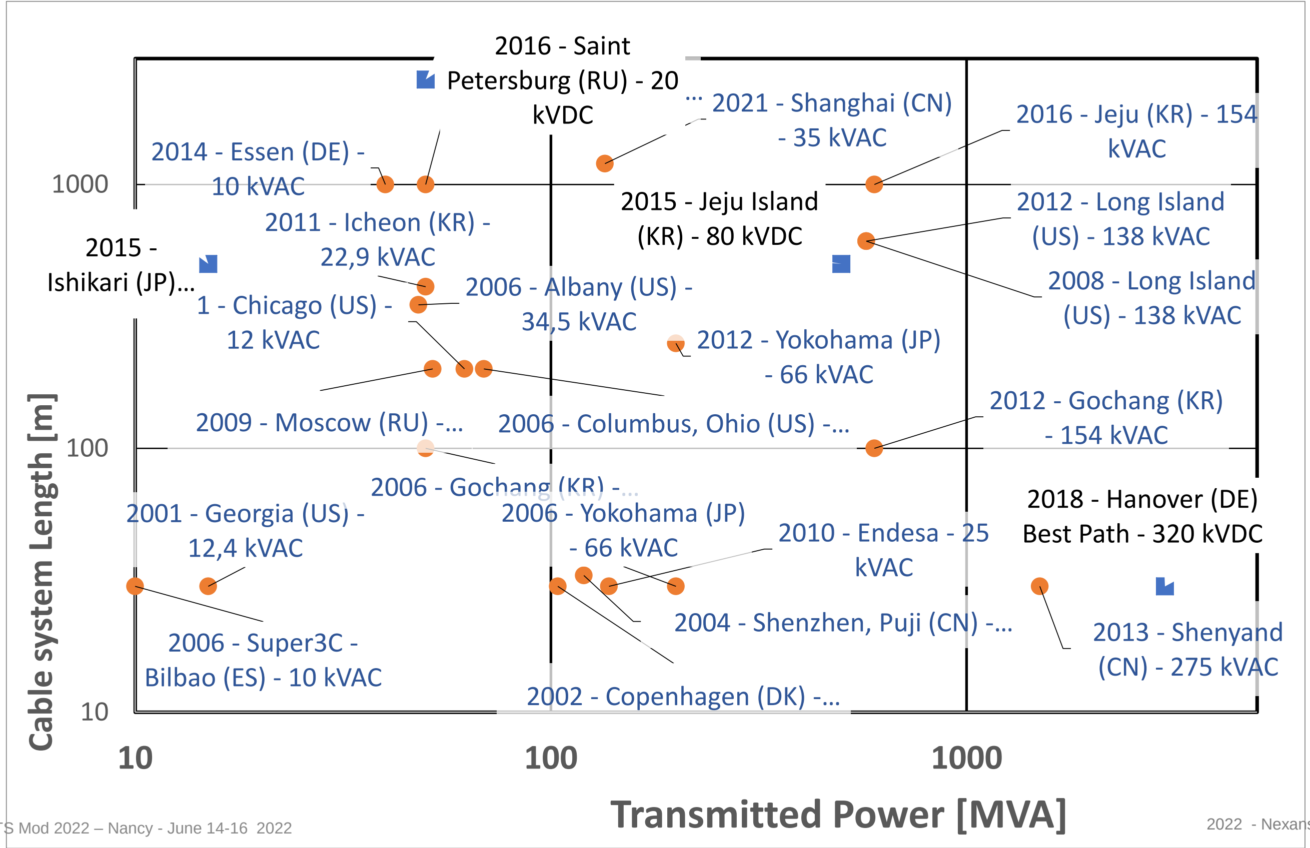
2 | 20 years of HTS systems in the grid

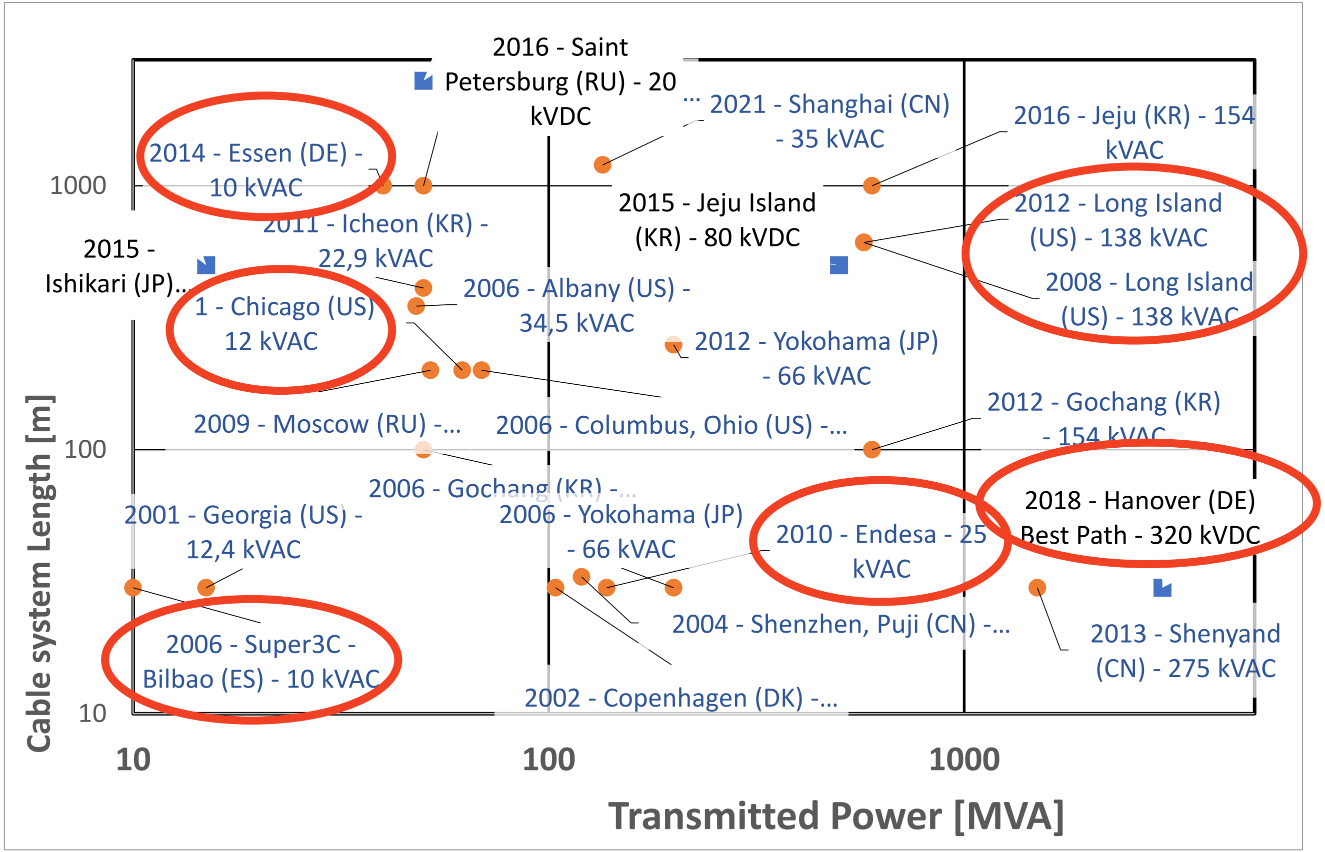
Map of HTS cable projects in the world



4 DC cables
21 AC cables

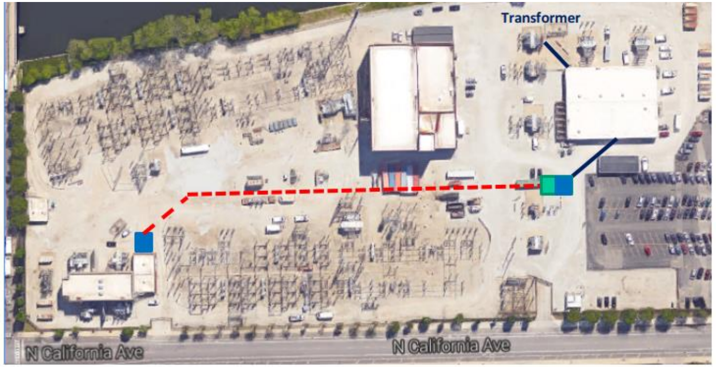
From 2001 to 2021

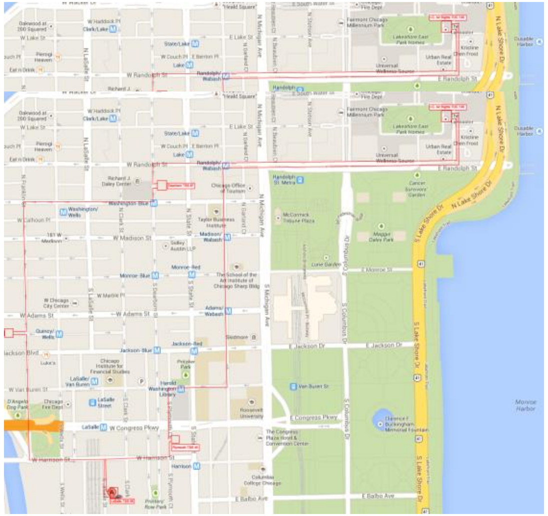
Focus on Nexans HTS cable projects



COMED - MVAC

- **200-meter 12 kV, 3 kA (62 MVA) HTS cable system**
- **Commissioned in ComEd substation during summer 2021**
- **Demonstrator preparing the connection of downtown Chicago substation through a high-capactity 5 km HTS loop at 12 kV**





AMPACITY MVAC project

AMPACITY Smart grids for the city

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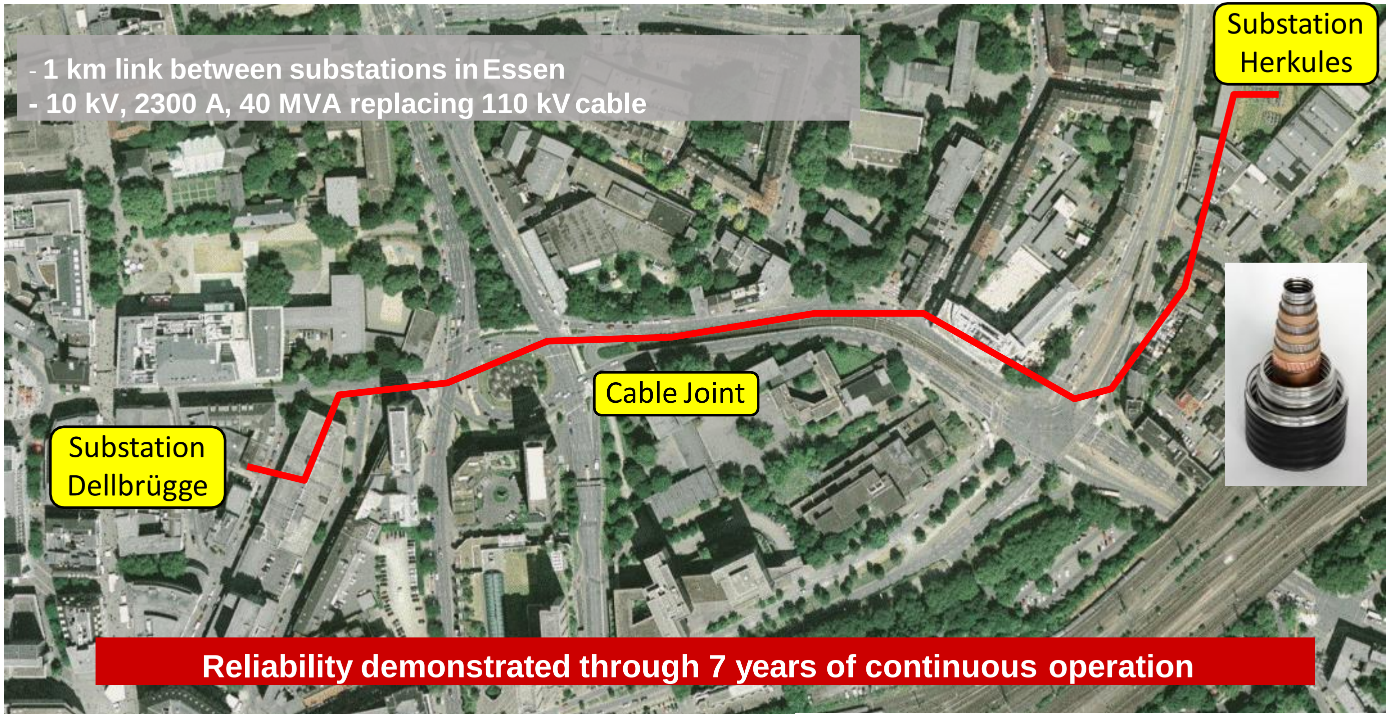
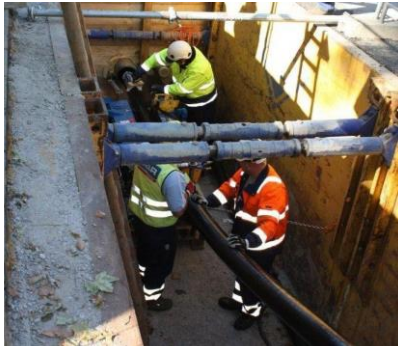


Luftbild: "Darstellung aus HK Luftbilder / Karten Lizenz Nr. 197 / 2012 mit Genehmigung vom Amt für Geoinformation, Vermessung und Kataster der Stadt Essen vom 13.02.2012"

AMPACITY cable installation



LIPA HVAC project in Long Island

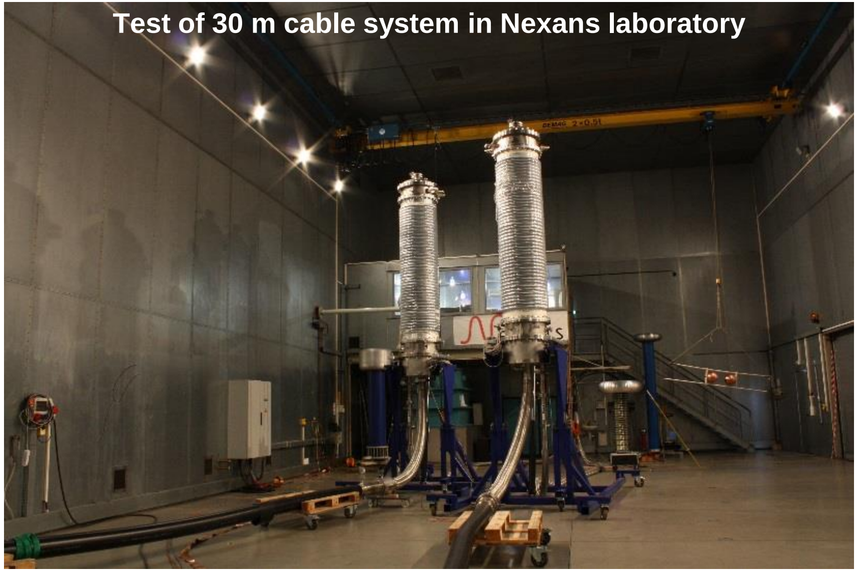
- **Cable connected to Long Island Power Authority Grid**
- **600 m HTS cable system**
  - 138 kV, 2,4 kA ~ 574 MVA
  - Specified fault current of 51 kA during 200 ms
- **Cable pulled in HDPE pipe**
- **Worlds first HTS cable operating at transmission voltage level**

European HVDC development project BestPaths

Length	30 m
Voltage	320 kV DC
Current	10 000 A
Power	3.2 GW


Cable core


Full cable



The production of 3 nuclear reactors can flow through this cable

Nexans HTS FCL in Europe

Take away from past FCL projects

What we learnt

- Liquid nitrogen cannot always be treated as network losses and re-invoiced to customers. Making it uncompatible with grid operator business model.
- The continuous supply of liquid nitrogen by trucks creates some logistics and environemental impacts that make the model unsustainable in urban areas.

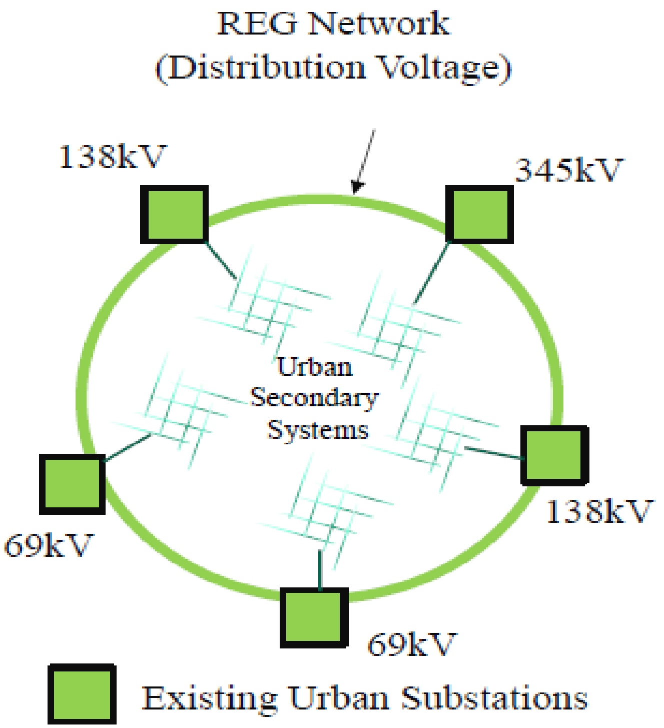
Trends for next projects

- In the future cryo-refrigerators are the prefered solutions.
- Need to improve cooling system efficiency and maintenance., especially for the range 1 to 5 kW@77K
- Production of liquid nitrogen from the air with a good level of purity (better than 99.5%)

3 NEXT STEPS

3.1 / COMED next phases
Targets of REG Networks using HTS cables

- REG Networks provide **resiliency** by creating grid **redundancy**
- REG Networks c**onnect** urban substations on the d**istribution side**, effectively **reinforcing** the transmission system
- REG Networks provide **high capacity, distribution voltage connections** with minimal footprint, civil work and permitting
- Approach is independent of **transmission voltage levels,** but compliments the existingtransmission system

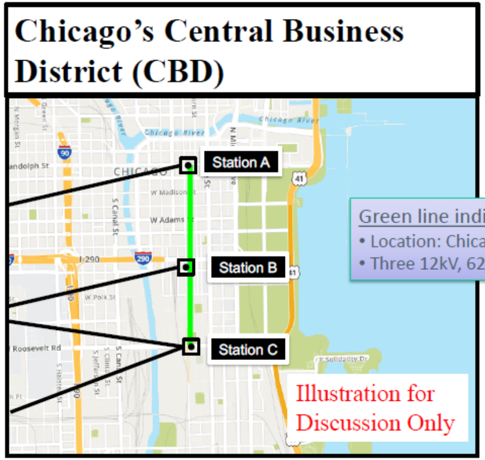


3.1 / Resilient Electric Grid (REG) Case using HTS cables in Chicago Central Business District

Intended to Provide Greater Resilience with Lower Cost and Less Disruption

Expected to increase reliability in the heart of the Chicago central business district

- **Two stations** are radial substations, served from 69kV sources. **One station** is looped at 138kV.
- Project intended to loop together all three substations into a network, increasing reliability and resiliency for all to N-3.
- **Expected to be far less disruptive** to the downtown core area than conventional transmission upgrades:
  - ➢ No **additional high voltage transformation**
  - ➢ No **significant infrastructure construction**
  - ➢ No **land acquisition for substation expansion**



Green line indicates superconducting cables:
- Location: Chicago's Central Business District (CBD)
- Three 12kV, 62MVA superconductor cables

3.1 / How can HTS cables increase the network resiliency?

There are many variations of what resiliency means, but fundamentally they all encompass the following three areas:

- **Withstand**
  - Eliminating or Preventing the event or resulting damage
- **Recover**
  - System and plans to provide rapid damage assessment and restoration
- **Survive**
  - The ability to maintain some basic level of electrical functionality

3.2 HTS solutions for Railways infrastructures

- SNCF constitutes a key customer for HTS cables and fault current limiters (FCL)
  - Technical team open to innovation
  - Partially-urban high-current MV network, both AC (25 kV) and DC (1500 V)
  - Facing strong challenges owing to increasing passenger traffic, over-used equipment, global warming leading to higher summer temperatures
  - Reference for addressing the world-wide railway infrastructure market

- Paris Montparnasse station
  - 200 000 passengers on working days and 750 trains per day on 28 tracks
  - Several electric breakdowns in the last years, including a blackout in July 2018 caused by a transformer on fire in the Issy-les-Moulineaux substation feeding Montparnasse

Launching of SuperRail Project to secure supply of Montparnasse thanks to HTS cables

3.2 Focus on SuperRail Project

Set-up	Consortium agreement with SNCF Réseau Industrial partners and academics
Main deliverable	Two 80-meter 1500 V DC, 3500 A HTS cables
Contracting scheme	Semi-turnkey : conception, cable system supply, installation, pulling and commissioning

3.2 / SuperRail objectives

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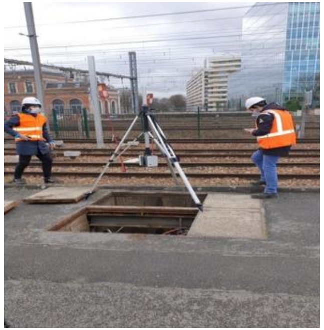
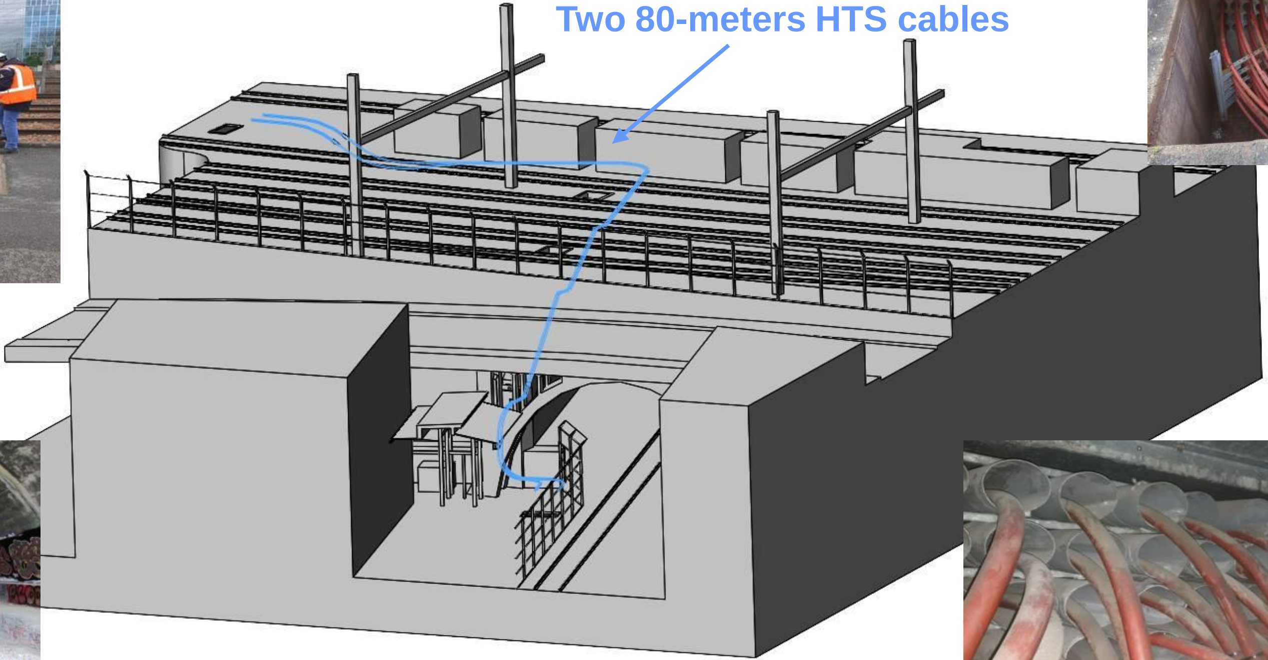
ENABLE TRAFFIC INCREASE IN PARIS MONTPARNASSE

- Bring power to Montparnasse tracks using pipes embedded in an old bridge
  - Copper cables cannot transport the required power through the existing pipes
  - Only HTS cables can meet this goal
- Develop the French academic expertise and industry on HTS technologies
  - Involvement of Centrale Supélec and Université de Lorraine
  - Cable core manufacturing in Bourg-en-Bresse (in addition to the usual development Calais)
  - Cooling system developed by Absolut System
  - Prototype loop testing in SNCF laboratory in Vitry-sur-Seine
- Anticipate the master plan for reinforcing the SNCF network

World's first HTS cable in a railway grid !

3.2 / SuperRail cable track





3.3 | MVDC HTS cables for offshore wind farm

3 MAIN DRIVERS HIGHLIGTED BY TSO

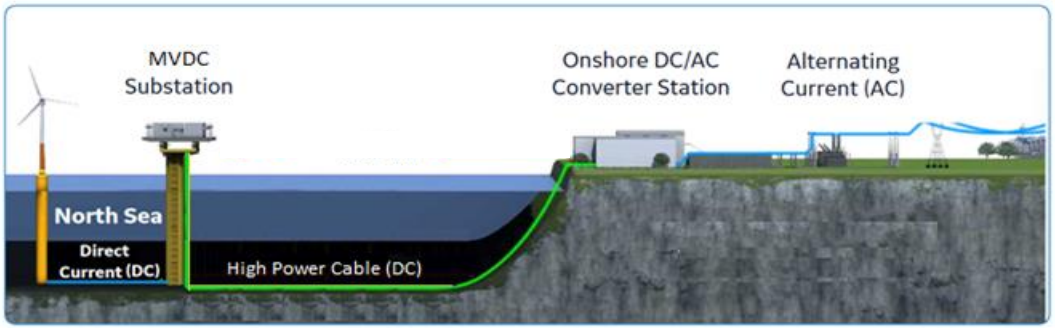
- MVDC is naturally present in the energy conversion chain of offshore wind mill
- Superconducting cables can transport very large DC currents with no electrical loss
- Expected drastic reduction of footprint on the offshore platform (only switching station, no need for large transformer)

2022 - Nexans Cryogenic and Superconducting Systems

3.3 | MVDC HTS cable - Expected performances

KEY PERFORMANCES

- ✓ At 50 kV DC, offshore power links of 1 GW/per dipole are being considered , meaning a current of 10 kA DC requiring a section of 50 mm² of superconducting tapes
- ✓ Very limited right of ways at cable landing (trench of 1 meter) with no thermal or electromagnetic impacts
- ✓ Low overall losses = ~1 MW/GW transmitted over 10 km
  - Only cryostat thermal losses in the range of 2 to 3 W/m (4 cryostats in // for 2 monopoles of 500 MW)
  - A cryogenic cooling station (TBF 1050) is consuming 12 W of electricty in order to evacuate 1 W in cryogenic conditions



3.3 | MVDC HTS cable - What has to be developped ?

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DEVELOPMENT STEPS REQUIRED

- For the superconducting cable system :
  - For cable length above 30 km = Intermediate Offshore platform for cryogenic cooling/pumping station,
  - Superconducting cable riser
  - Submarine joint

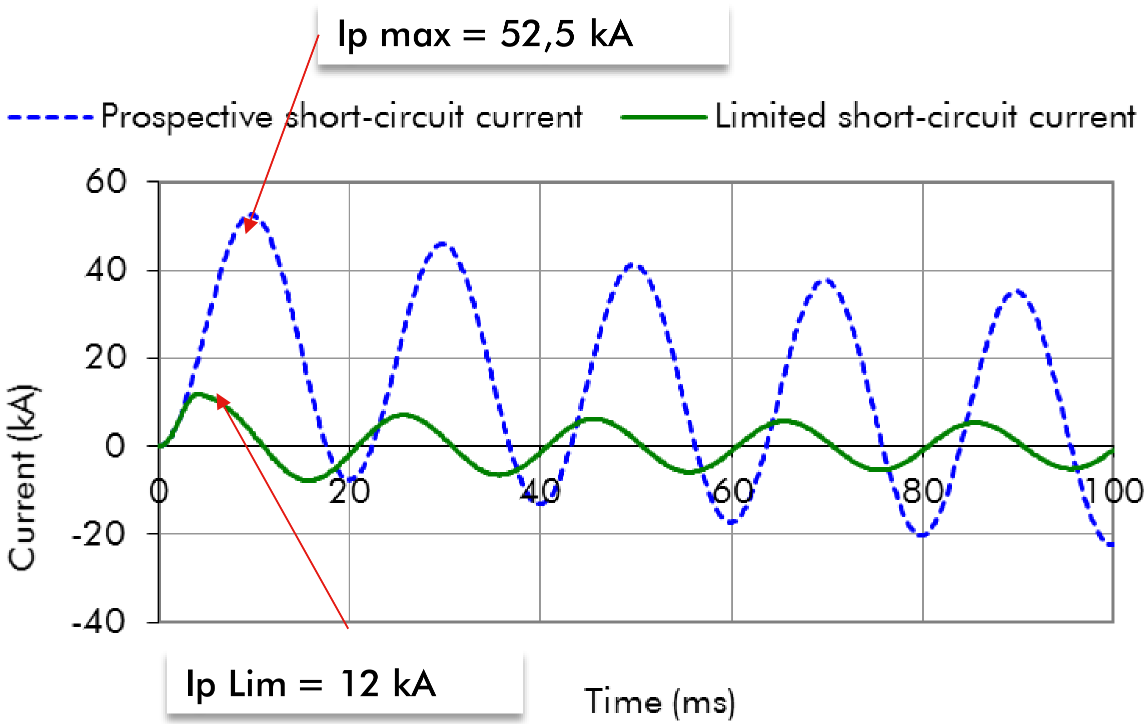
- For wind farm system components :
  - Output at 50 kV DC for wind mills
  - High current conversion (> 10 kA) station in the land power substation (PCCT)

3.3 | Key benefits of MVDC HTS cables

Offshore wind farms can benefit from superconducting cables through

- Lower losses, especially for system of 1 GW or more
- Reduced offshore foot print
- Smaller cable landing area

1.4 / Application of HTS FCL in Railways Networks



Rated Voltage	25 kV (monophasic)
Rated current	2000 A
Fault duration	100 ms

1.4 / Status of on-going FCL projects

Distribution grid

Europe = Numerous pilot and studies in the last 10 years but grids are not yet enough saturated to require FCL.

US = Simulations of future upgrade scenario of city center sub stations shows that FCL could save up to 100 MW of supply power in case of fault.

Railways networks

Short term pilot : :

- Increase of high-speed train traffic
- Transformer and breaker protection

Long term prospective : :

- 25 kV Transformer cost reduction
- Increase of supplied power by 1500 VDC stations

4 Need for a new modeling approach in industry

Status of modeling for grid HTS solutions

The aim of actual modeling activities for HTS cable and FCL is- to make sure that the superconducting systems are :

- designed to answer to customer specification
- safe during operation (fault events)

The questions raised by customers on the everyday life of HTS system show that we have to go further to use the full potential of supercondcutors :

- we need to model the full dynamic of the system all along the differents life cycles (cooling down, warming up, recovery after fault…) , expecially including the cooling system capacities and control

Need for dynamic models in HTS applications

Transient models of FCL :

- Adabatic/Electrical FCL behaviour
  - Resistance as a function of dissipated energy
  - For a range of designs to be defined with customers (library)

……to be associated with an active use of cooling system especially in recovery phases.

For HTS cable + cooling system :

Full Transient thermal model in order to optimize :

- Cooling down
- Warming up
- recovery after fault
- …. other events brought by customers

Goals of Twin models of HTS systems

Dynamic Models of HTS cable or FCL with their associated cooling system aiming at :

- developing and deploy automation programs for HTS systems
- giving planners models to anticipate the impacts of the integration of HTS solutions in the grid
- evaluating energy consumption and carbon footprint related to real load curves in HTS systems life cycles

Conclusion

Conclusions

- HTS cables and Resistive Fault current Limiters are mature technologies, industrially produced
- HTS solutions answer to the challenges of energy transition in city centers where space is limited, and civil works are very disruptive :
  - ***To secure and reinforce distribution grid***
  - ***To increase Train/Tram/Metro traffic, and e-mobility in general in the future***
- Modeling is a powerful way for HTS solutions to be considered by planners and engineers at the very early stage and make possible projects of grids expansion or reinforcement that are not possible or very disruptive with conventional technologies.