220 kV HTS-Strombegrenzer für das Stadtnetz in Moskau

1896 Electrical illumination of Moscow

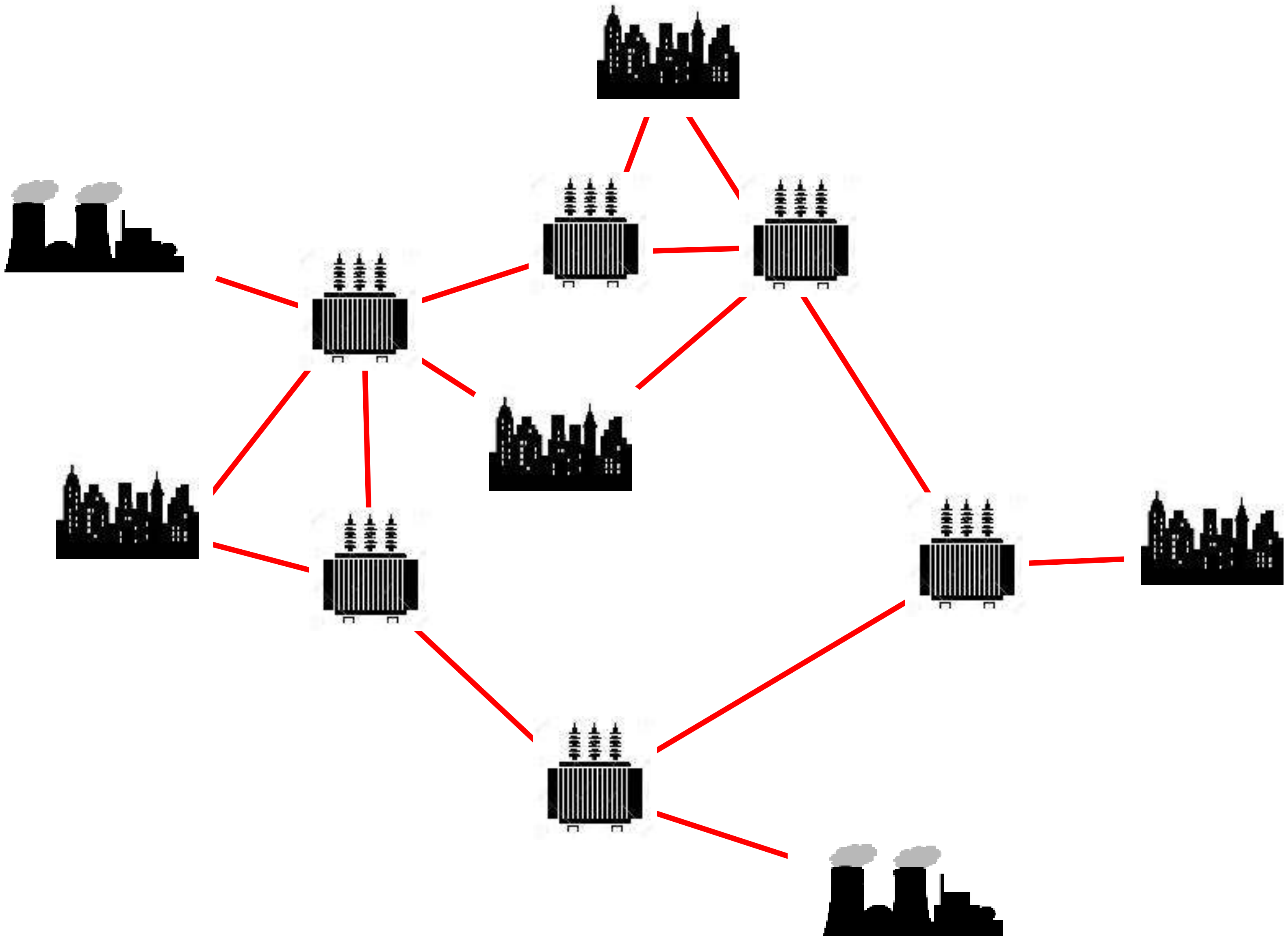
2020 Electrical illumination of Moscow

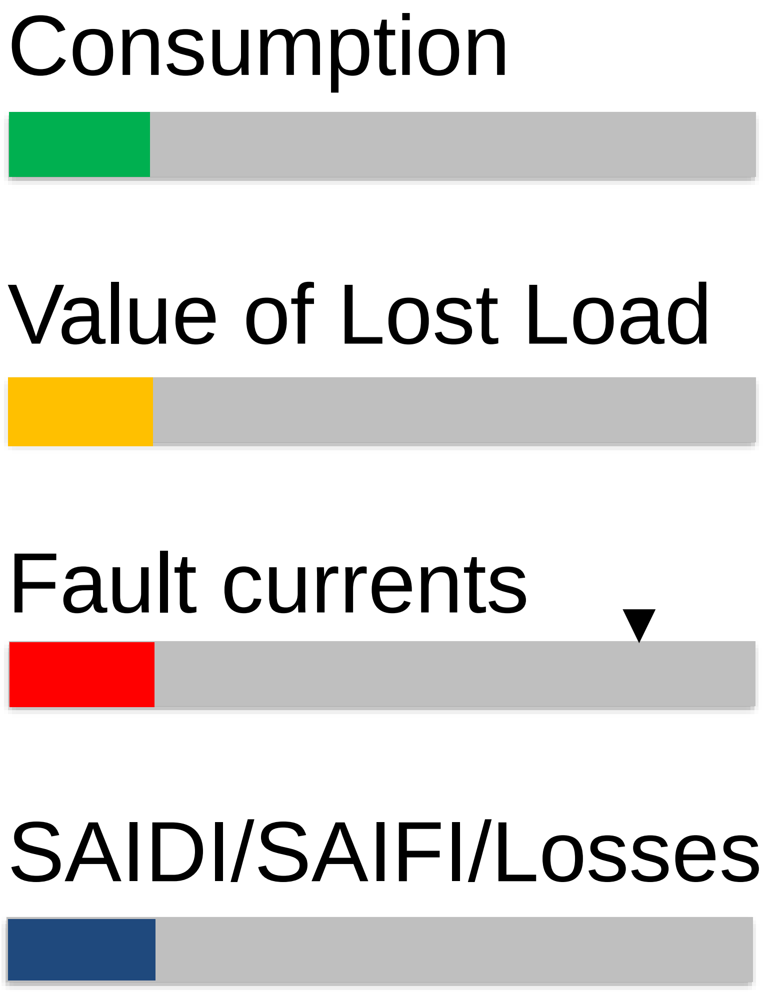
Moscow electrical grid

SuperOx

Electrical grid parameters	Russia	Moscow
Installed generation capacity	246 GW	**17 GW**
Electricity consumption	1059 TWh / year	**108 TWh / year**
Consumption growth rate	+23% / 20 years	**+ 59% / 20 years**

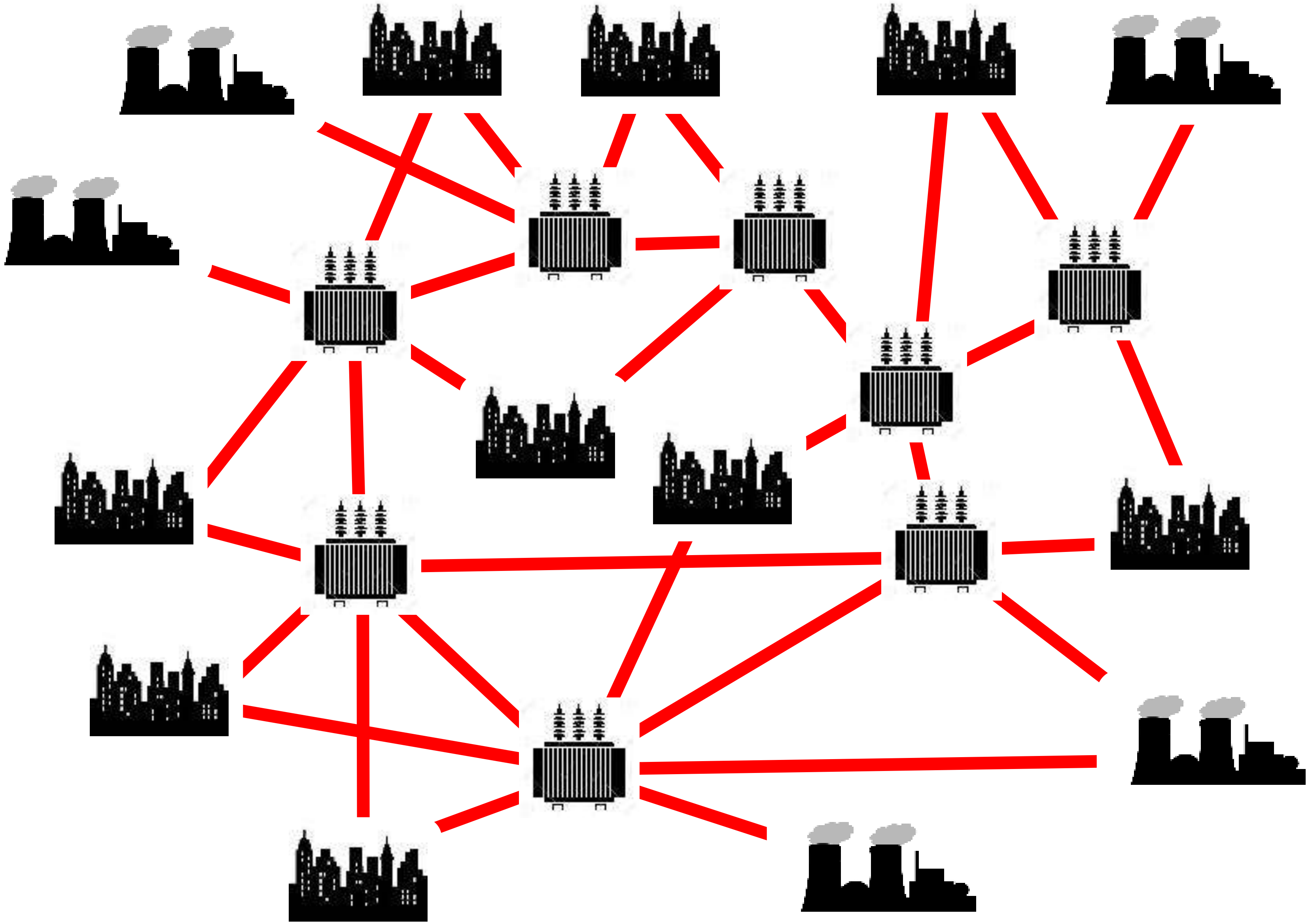
Electrical grid of megapolices

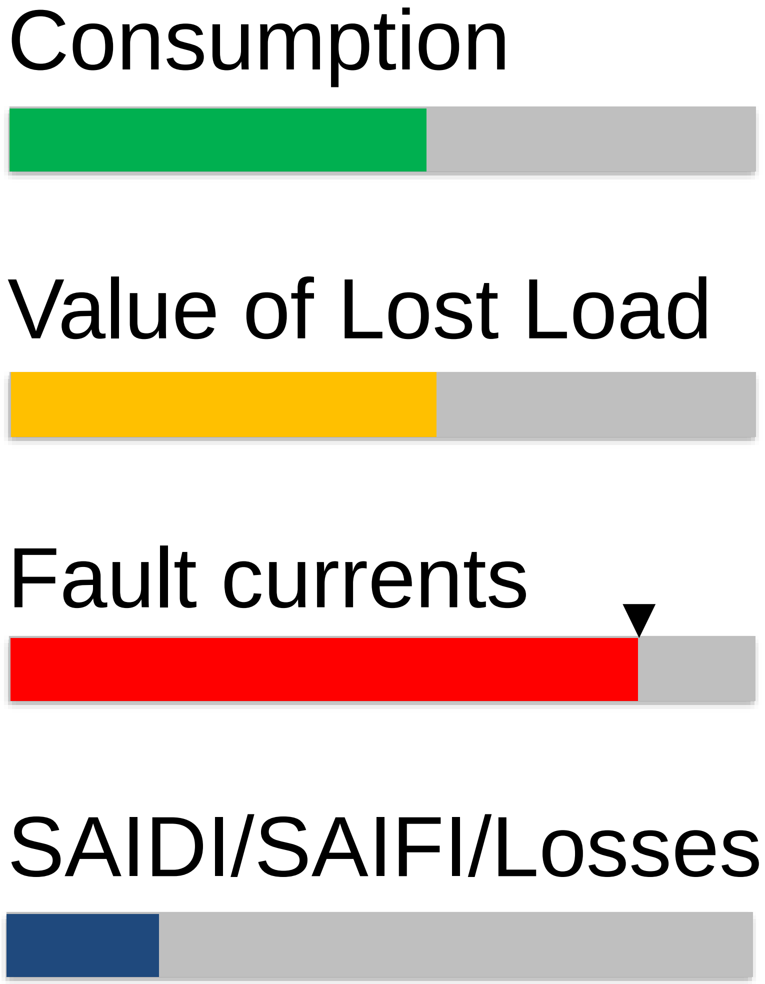




Electrical grid of megapolices

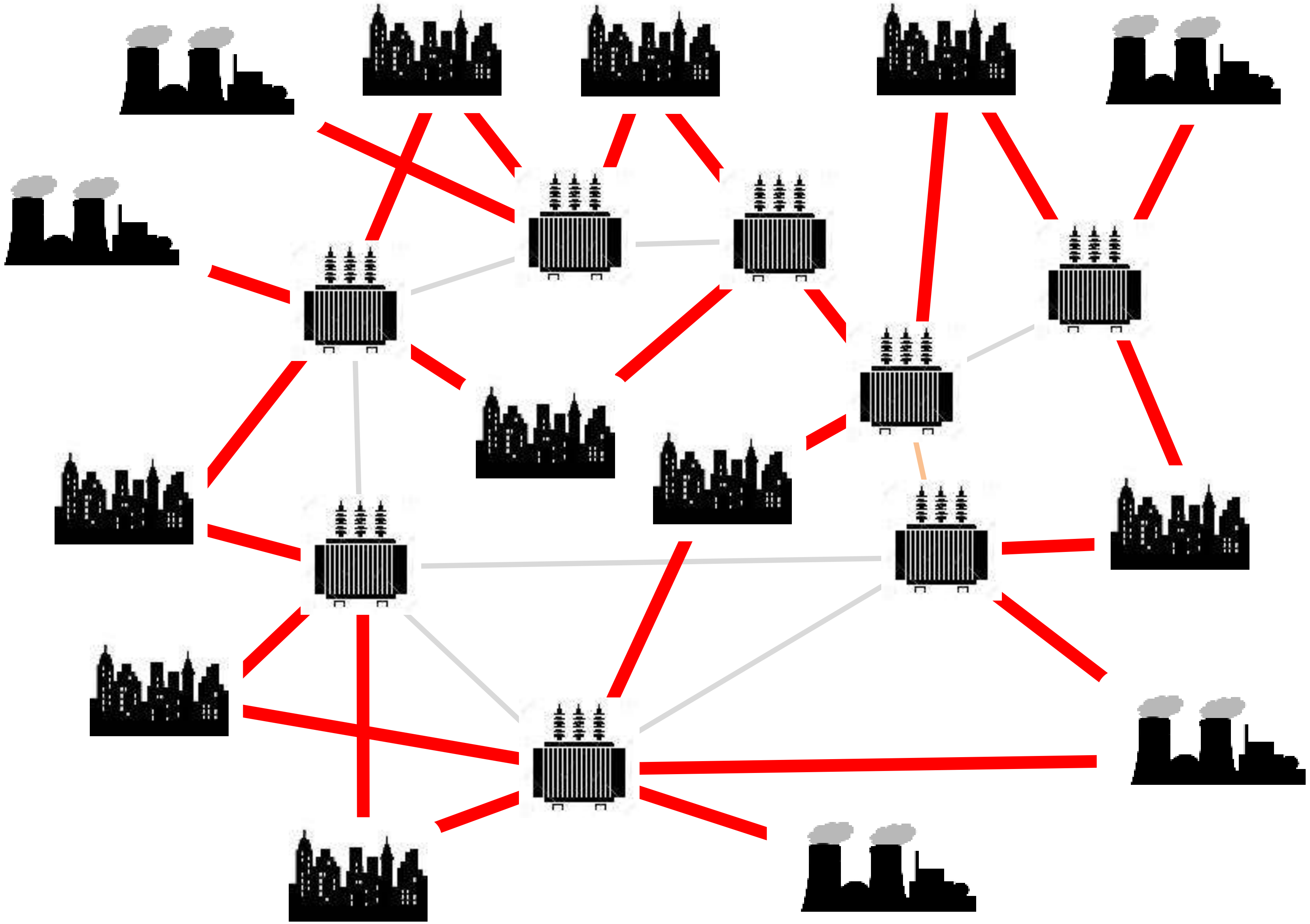
SuperOx

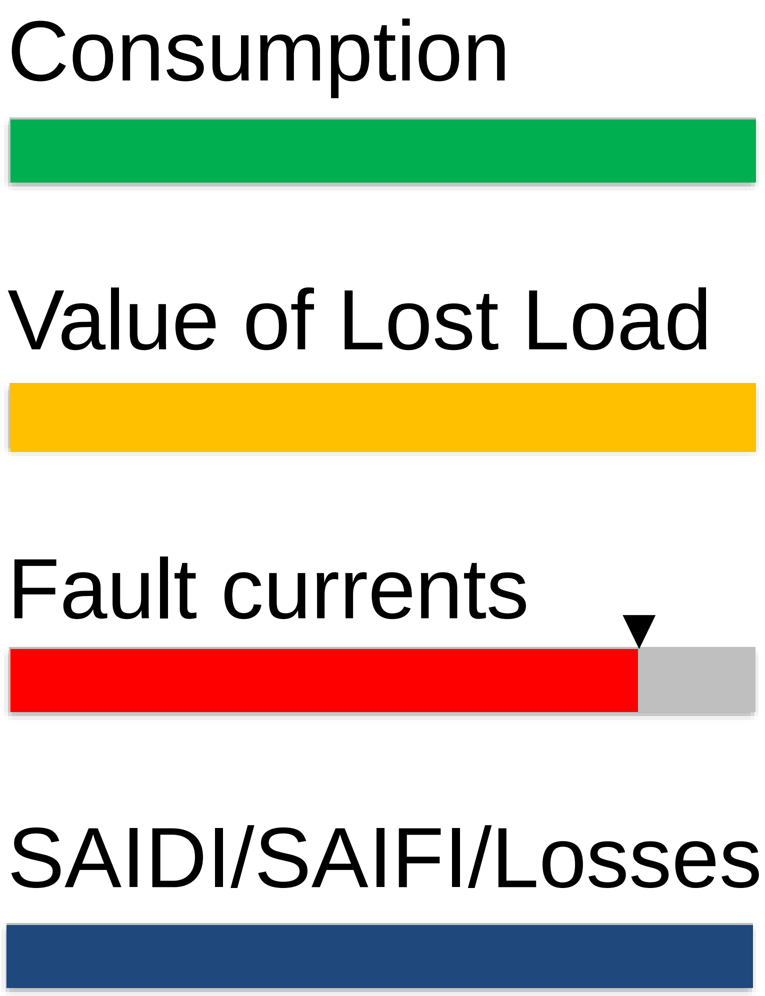




Electrical grid of megapolices

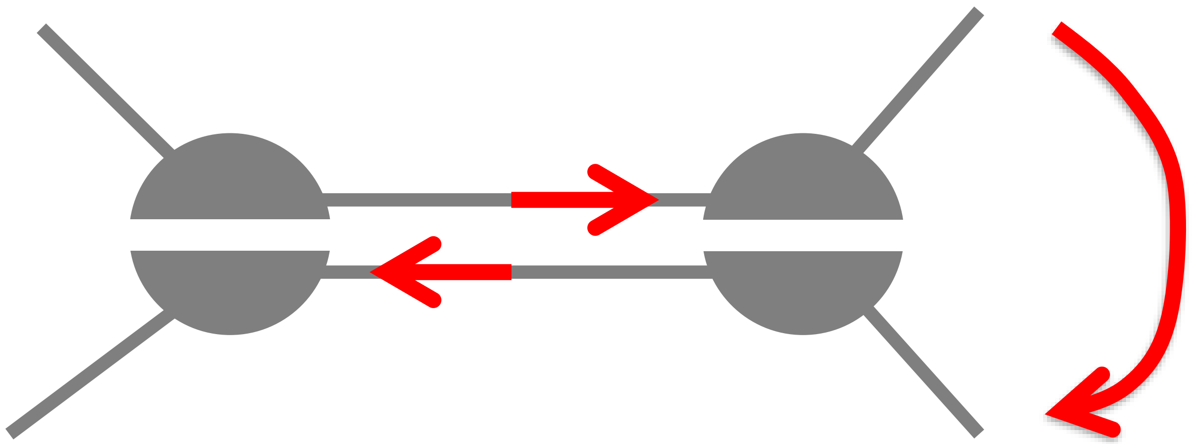
SuperOx



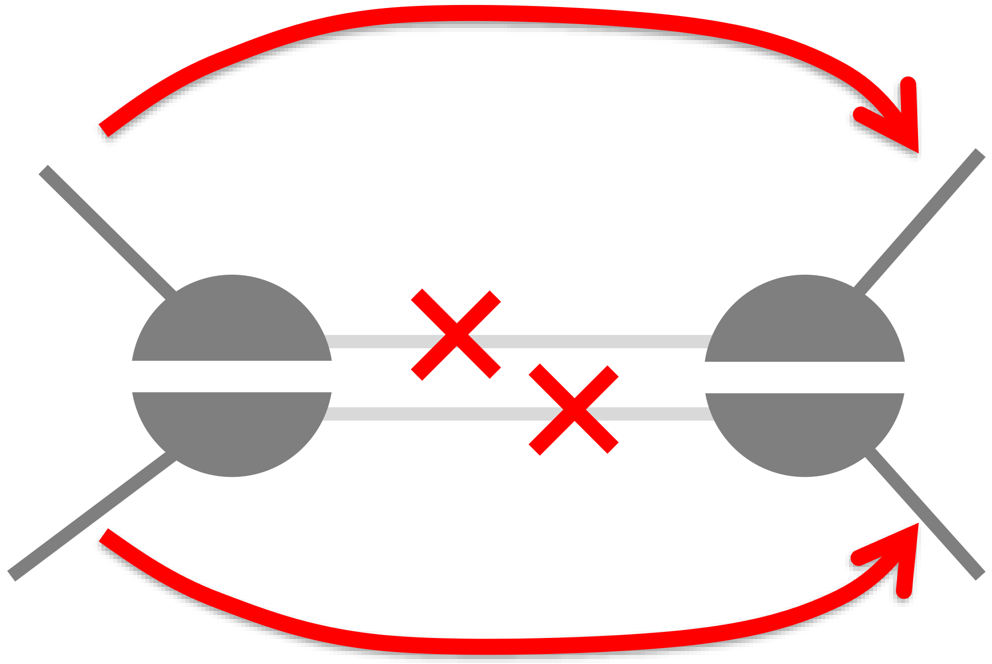


Consequences of sectioning the grid

SuperOx



Bus bar sectioned:
power flow in opposite directions



Cables lines sectioned:
transmission is off

Moscow electrical grid

SuperOx

Rapid growth of consumption

Generation located inside the city

Short distance transmission

Cables instead of overhead lines

⟶ Growth of fault currents

Mitigation of fault currents in the grid

SuperOx

Sectioning the grid → Grid redundancy suffers

More complicated to operate

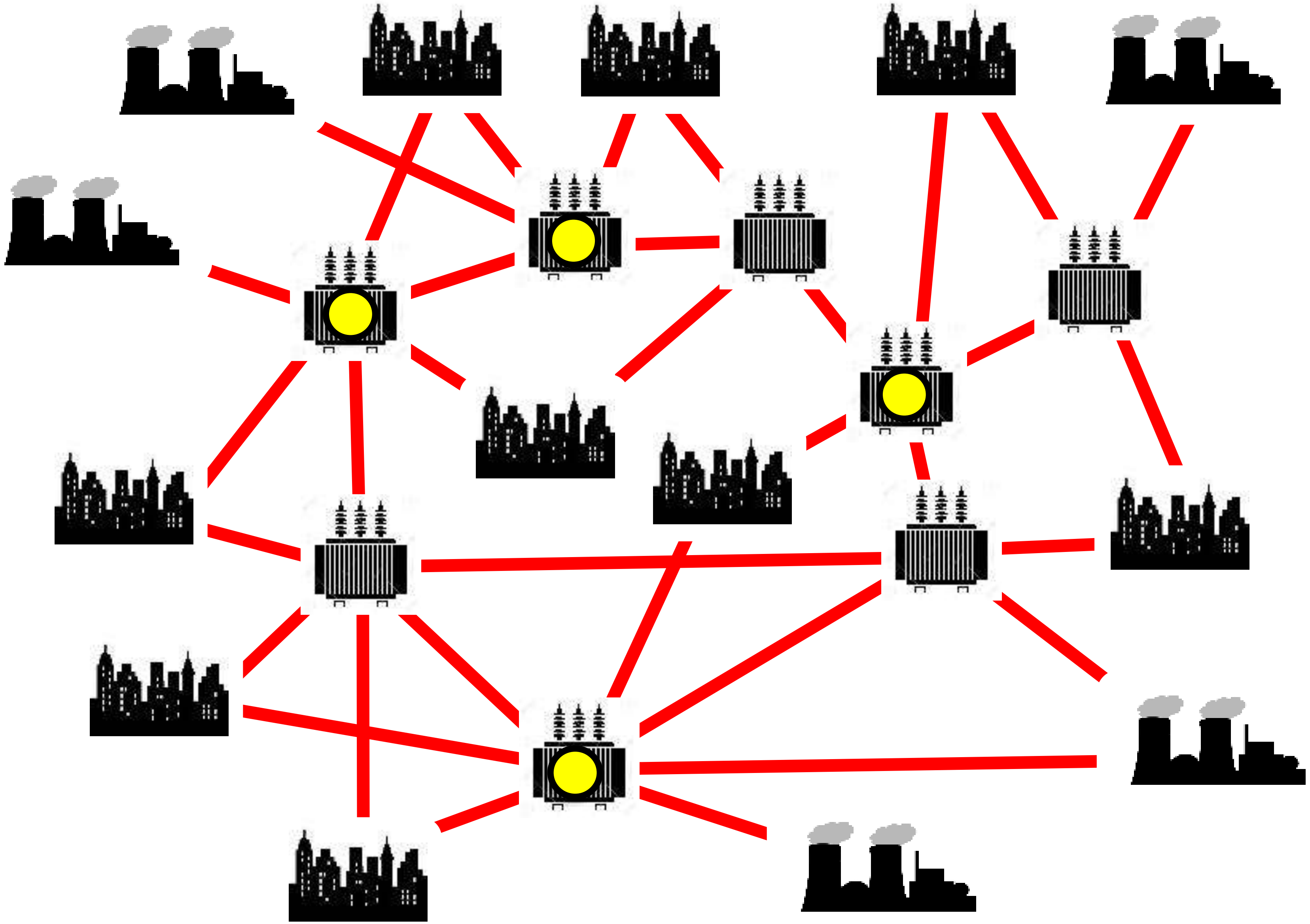
Install air core reactors → Losses

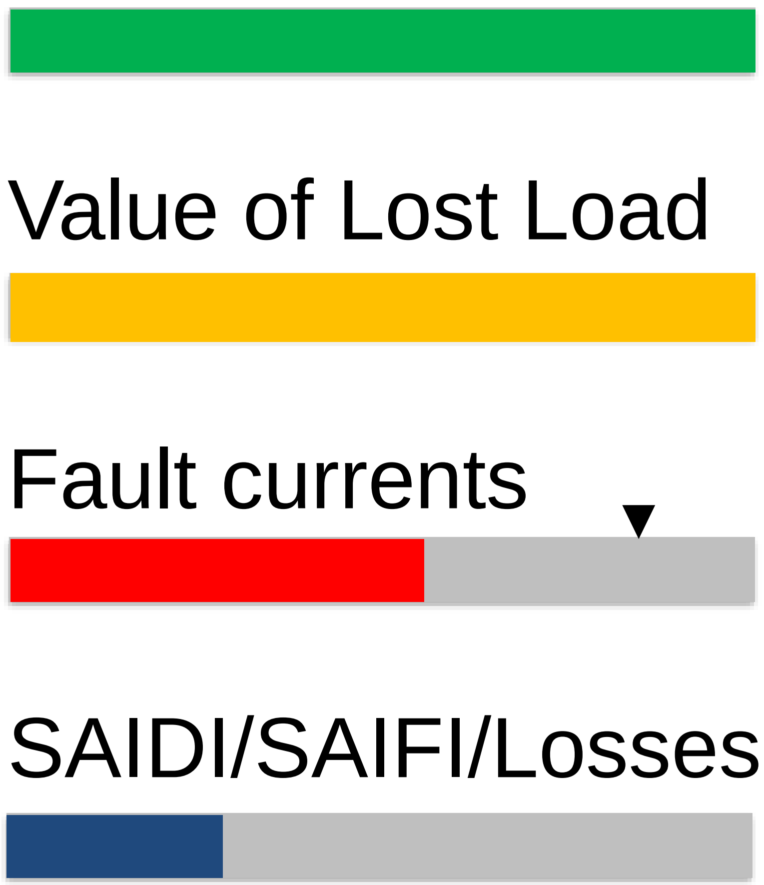
More impedance needed

Install fault current limiters

Electrical grid of megapolices (+SFCL ●)

SuperOx

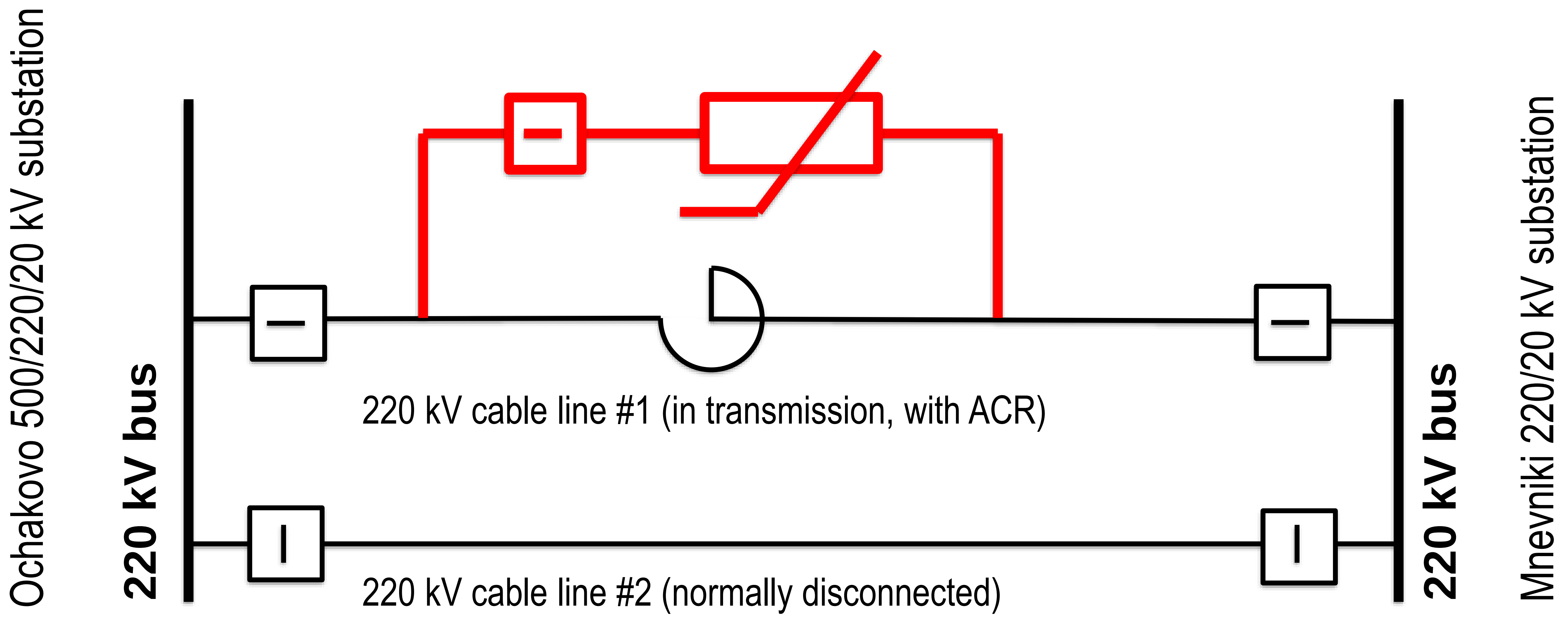




A pilot project – 220 kV SFCL for Mnevniki substation (UNECO)

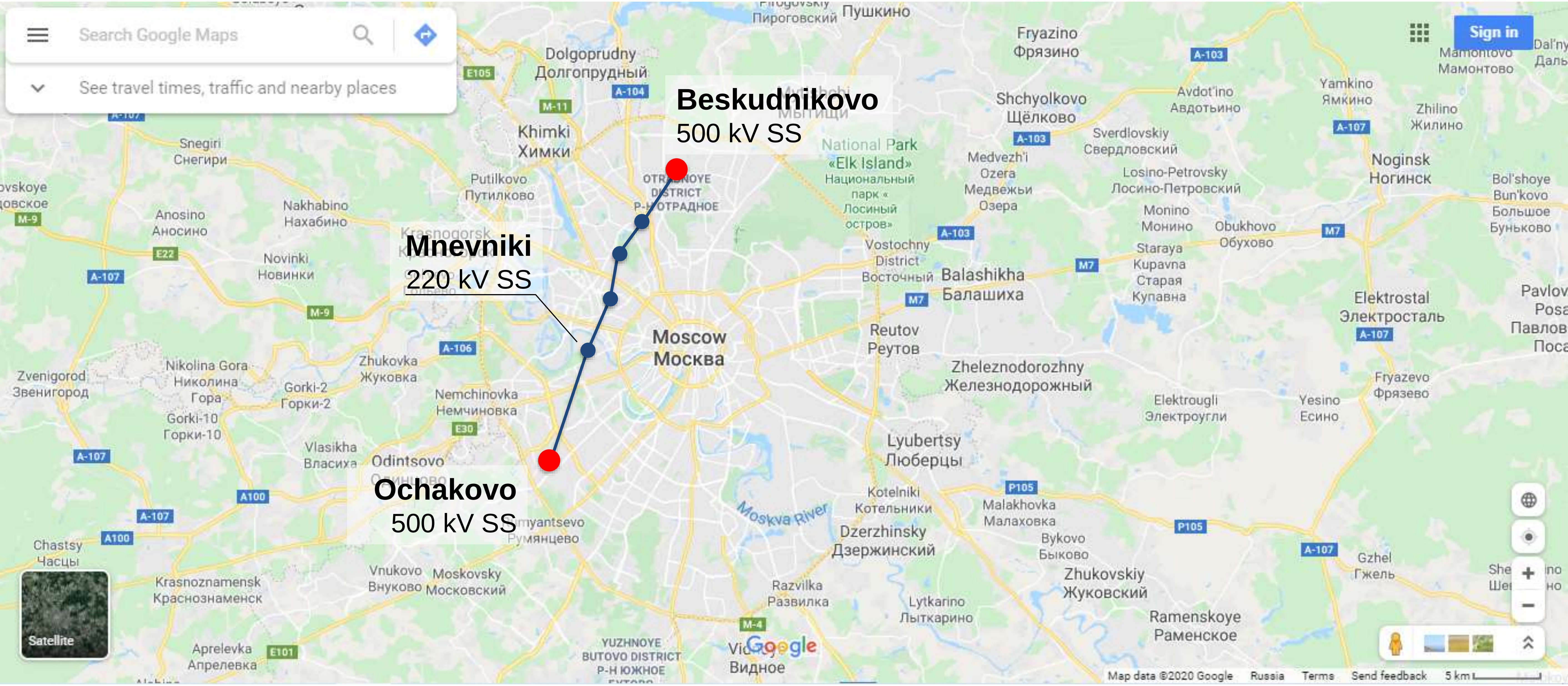
SuperOx

Installation of 40 Ohm SFCL in parallel to existing 3.0 Ohm ACR



A pilot project – 220 kV SFCL for Mnevniki substation (UNECO)

SuperOx



Specifications of 220 kV SFCL

SuperOx

Property	Value
Nominal voltage	220 kV rms
Maximum operation voltage	252 kV rms
BIL test voltage	950 kV
AC withstand voltage	440 kV rms
Nominal frequency	50 Hz
Nominal current	1200 A rms
Critical current	3400 A peak
Nominal operational resistance	< 0,01 Ohm
Fault current limiting resistance	> 40 Ohm
Transition time	< 2 ms
Type of placement	Open
Climate requirements	-45 deg C … +40 deg C
Size of 1 phase (LxWxH)	5500 x 2850 x 6500 mm
Weight of 1 phase (dry / with nitrogen)	16/27 ton

Full development cycle – from HTS wire to power system

SuperOx

Superconductor wire development and production

High currrent conductor design and production

Superconductor module and assembly engineering and production

Corona rings system HV engineering and production

Solid state bushings engineering and production

Closed cycle cryogenic system design and production

Assembly of SFCL phases, logistics to test sites

High voltage and power tests

Logistics of equipment to substation

Civil engineering work at substation

Electrical, magnetic, thermophysical, mechanical modelling

State expertise (price and technical inspection)

Regulatory paperwork (relay protection, technical regulations, etc.)

Component engineering

Solid state cryogenic bushings (950 kV BIL tested)

Cryostat with two manholes (15 bar tested)

HV coordination (1 min @ 440 kV rms tested)

Superconductor assembly (HV and Power tested)

Composite mechanical support (HV and load tested)

Component testing

Each component of 220 kV SFCL was rigorously tested in leading world labs since 2014

Engineering was refined until all the components passed strict technical requirements

HTS modules
Russia

Current leads
Russia

Cryostats
Korea

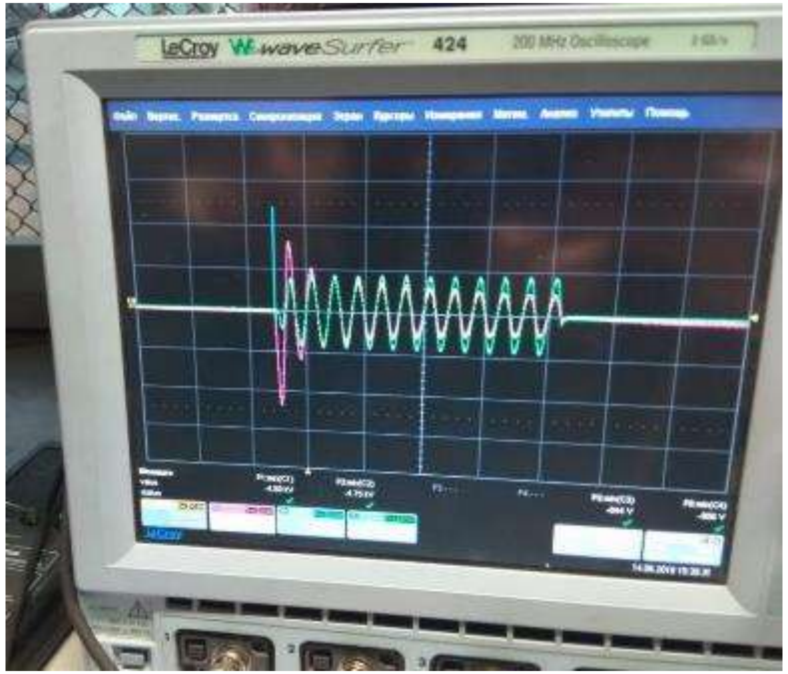
Cryocoolers
Japan

Current leads
Korea

HTS modules
Russia

System testing

- Three phases of 220 kV SFCL were tested after IEEE C37.302-2015 guide
- Test program developed jointly by SuperOx and UNECO
- A number of successful tests completed :
  - Acceptance tests of each phase of the device in KERI (Korea)
  - Operational tests at substation (HV, EMI, cooling system, automation)
  - Real time digital simulation (RTDS) tests of relay protection systems



HV and power tests of 220 kV SFCL

SuperOx

Power record of current limiting:

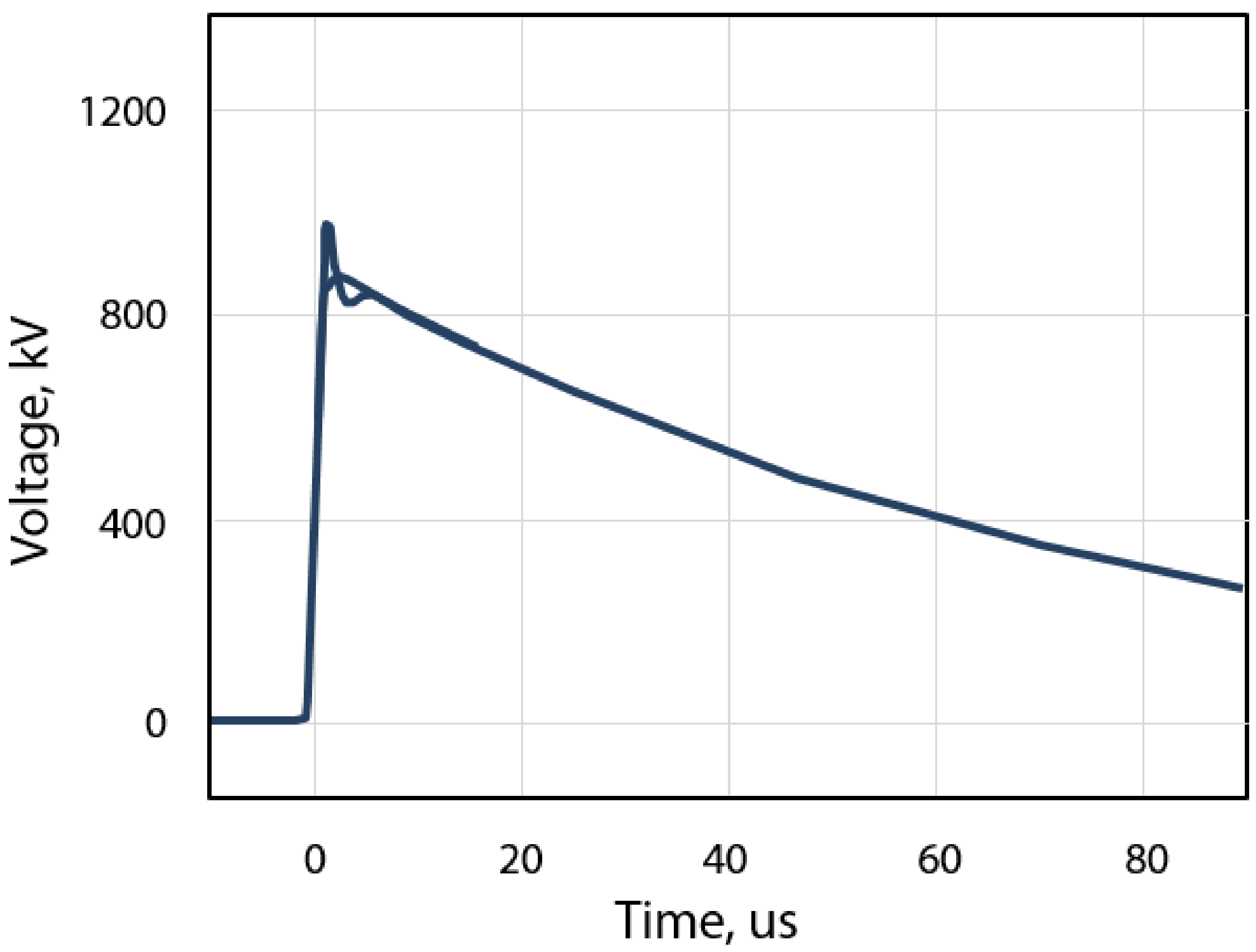
2000 MW → 300 MW

Name of the test	Value confirmed
Lightning impulse	950 kV, 1.5/50 us
Power frequency overvoltage withstand	440 kV, 1 min
Partial discharge	Less than 25 pC
Rated current	1200 A
Short-term overcurrent	2000 A
Short-circuit current	38 kA -> 6.8 kA

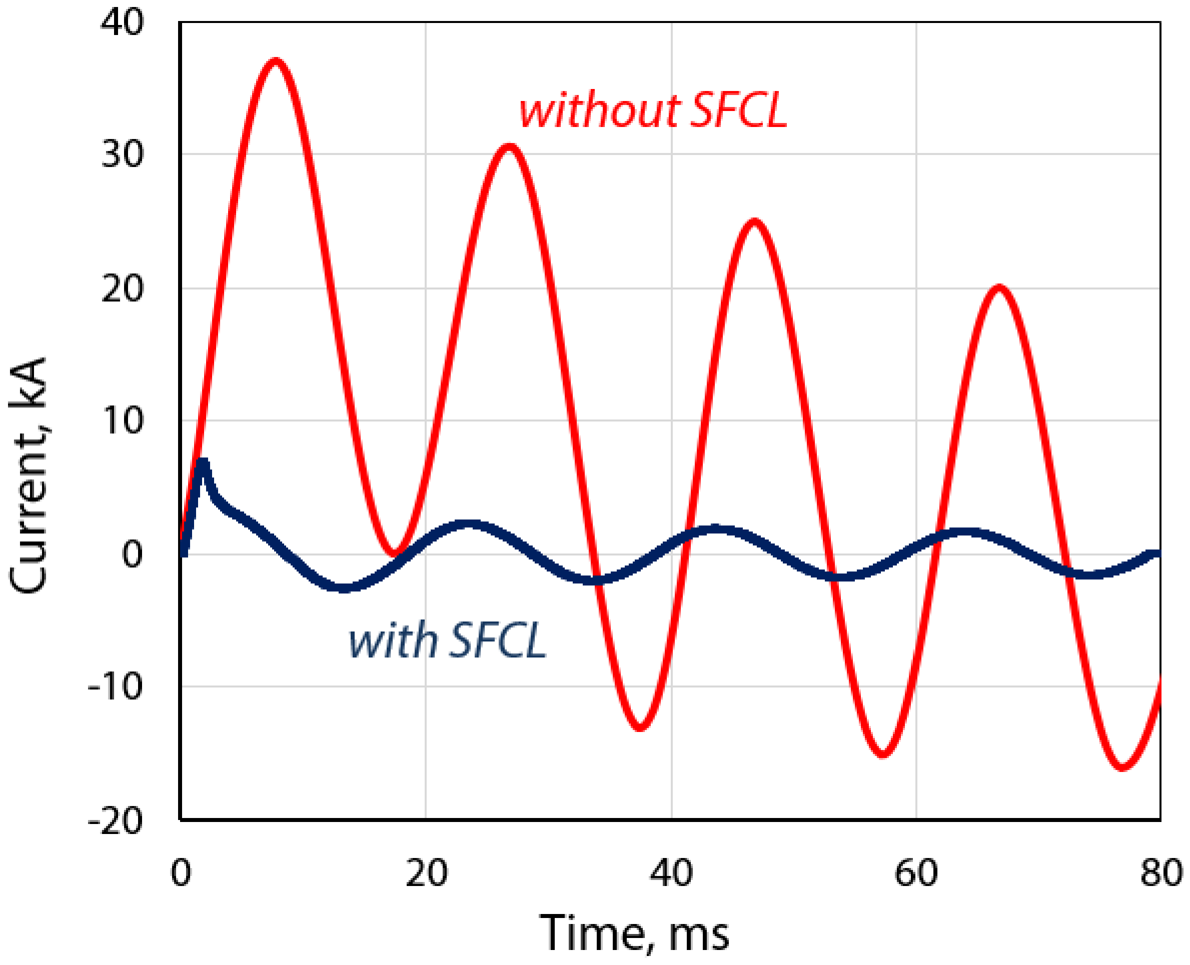
220 kV SFCL phase at the test site in KERI (Korea)

HV and power tests of 220 kV SFCL in KERI

SuperOx



950 kV lightning impulse test

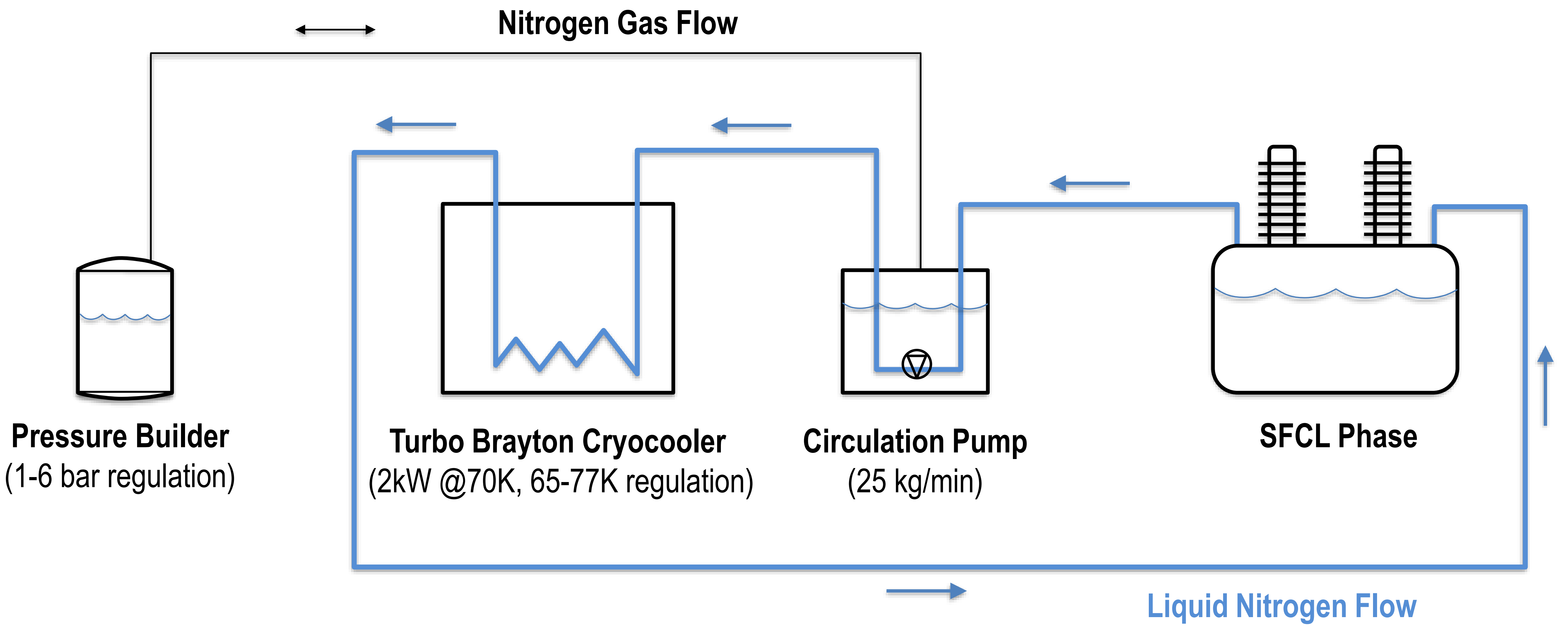


High power test

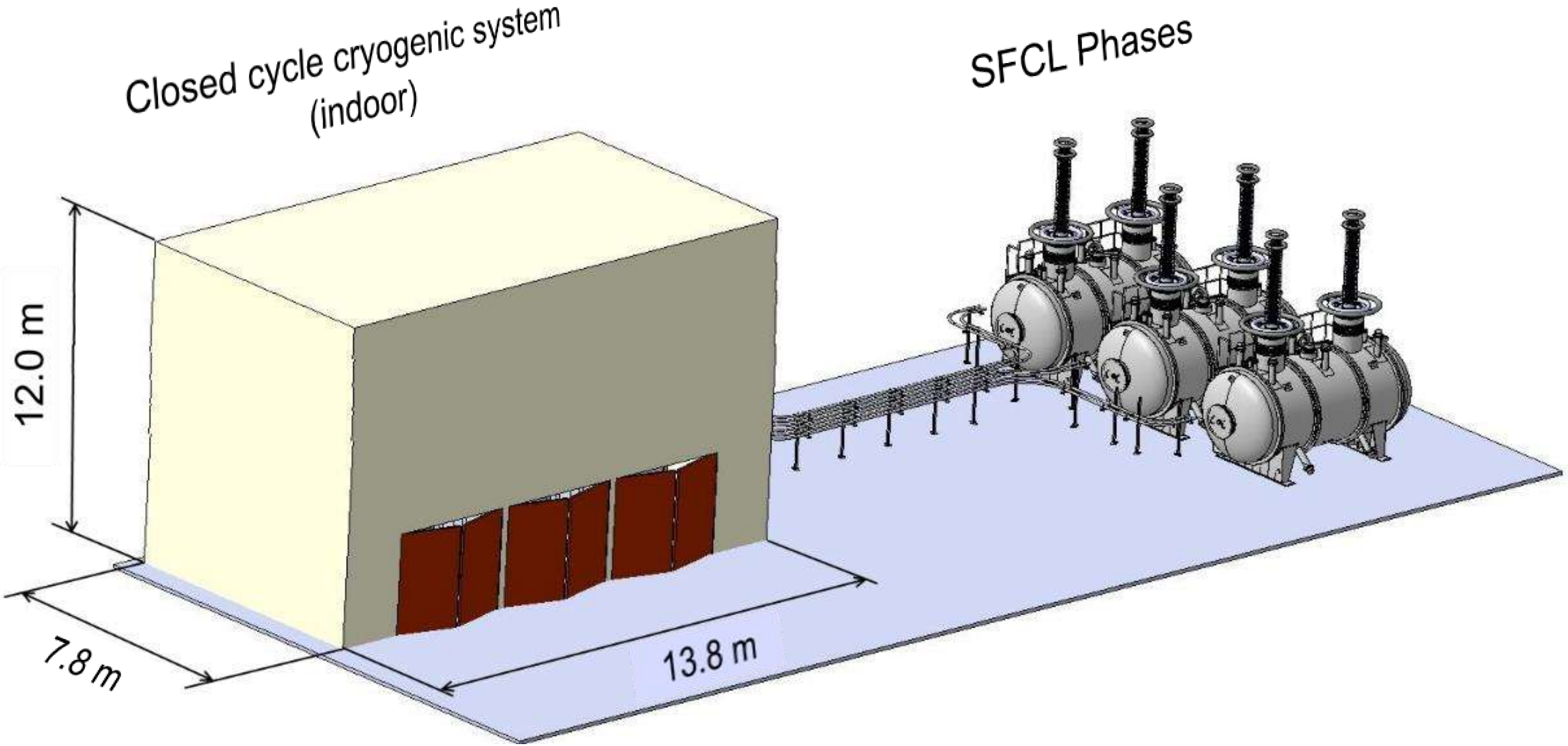
Cryogenic system design

SuperOx

Each SFCL phase is equipped with it’s cooling sub-system. By-passes provide redundancy.



Installation site planning



Timeline of the 220 kV SFCL project

SuperOx

2019 | 2018 | 2017 | 2016 | 2015

Project (first phase)

State expertize

Project (second phase)

Start to build equipment

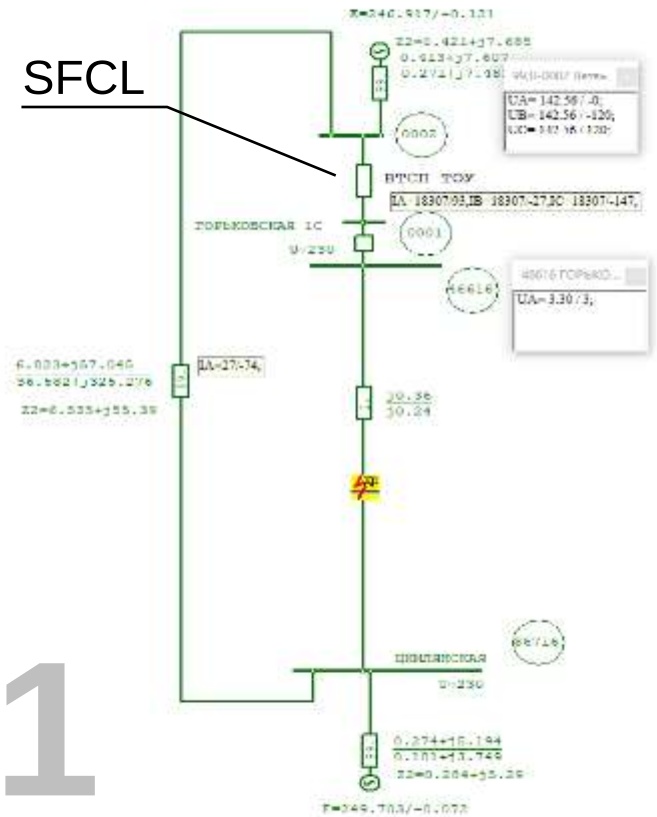
Start of civil construction
Start to install equipment

Comissioning & tests

Fully operational

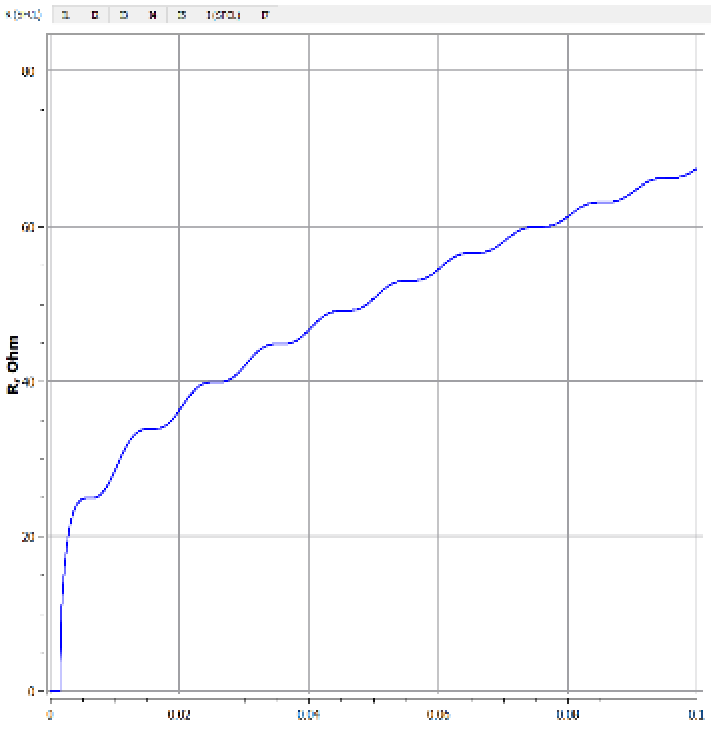
Mathematical model of SFCL for relay protection coordination

SuperOx



1

Power grid with SFCL is modelled



2

SFCL resistance *vs* time is calculated with a verified mathematical model

3

Р Е З У Л Ь Т А Т Ы   Р А С Ч Е Т А на уровен
Ом

1-Пояс Узла	Наименование Узла	3х-фазное КЗ I1(мод/фаза)	
U=250.7/-0 Z1=0.133+j5.194 Z2=0.13			
21416-	ОЧАКОВО 1С	27862	91
0,8	Общая нейтраль	0	0
21411,1	ОЧАКОВО	9460	90
21467,66	ОЧАКОВО АТ	3745	95
85726,1	НИКУЛИНО 2С	0	91
C2536,3	ТЭЦ-25	3425	90
N0926	МНЕВНИКИ	9	134
N8126	СОЮЗ	11234	92
U=549.2/-0 Z1=0.200+j7.460 Z2=0.20			
21418-	ОЧАКОВО	42485	91
21411,1	ОЧАКОВО	2355	91
21421,2	ОЧАКОВО	3049	91
21430,3	ОЧАКОВО	3204	91
21444,44		2716	91
C2518,7	ТЭЦ-25	1495	90
C2528,8	ТЭЦ-25	2132	90
C2618	ТЭЦ-26	15689	91
N8418	ПП ОЧАКОВО	11853	93

Grid operation determined:
- Switchgear capacity verification
- Relay protection setup
- Real time digital simulation

System Operator regulations have been developed for operation of grids with SFCL

Regulatory paperwork – a lot is done!

- High voltage and power SFCL test program based on IEEE C37.302-2015 guide
- SFCL model user manual for relay protection coordination calculations
- Methodology for calculating compatibility of switchgear in the grid with SFCL
- Test program for relay protection devices for RTDS test bench for grids with SFCL
- Methodology for calculating relay protection devices in grids with SFCL
- Instruction manual for substation duty personnel in relation to SFCL
- SFCL user manual
- Program for taking SFCL in grid operation
- General Technical requirements for 220 and 110 kV SFCL at substation
- Draft of national standard for high voltage SFCL

Conclusions

- SuperOx developed a full scale technology of high voltage SFCL
- 220 kV SFCL was built and extensively tested after IEEE C37.302-2015 guide
- The closed cycle turbo Brayton cryogenic system was developed and used
- Solid-insulation current leads / bushings were developed, tested and used in SFCL
- First 220 kV SFCL at the 220/20 kV substation in Moscow was energized in Dec. 2019
- Further projects are in consideration by two grid companies (4 SFCLs in total)

Acknowledgement

SuperOx SFCL Team, June 2019

SuperOx

Thank you!

www.superox.ru/en