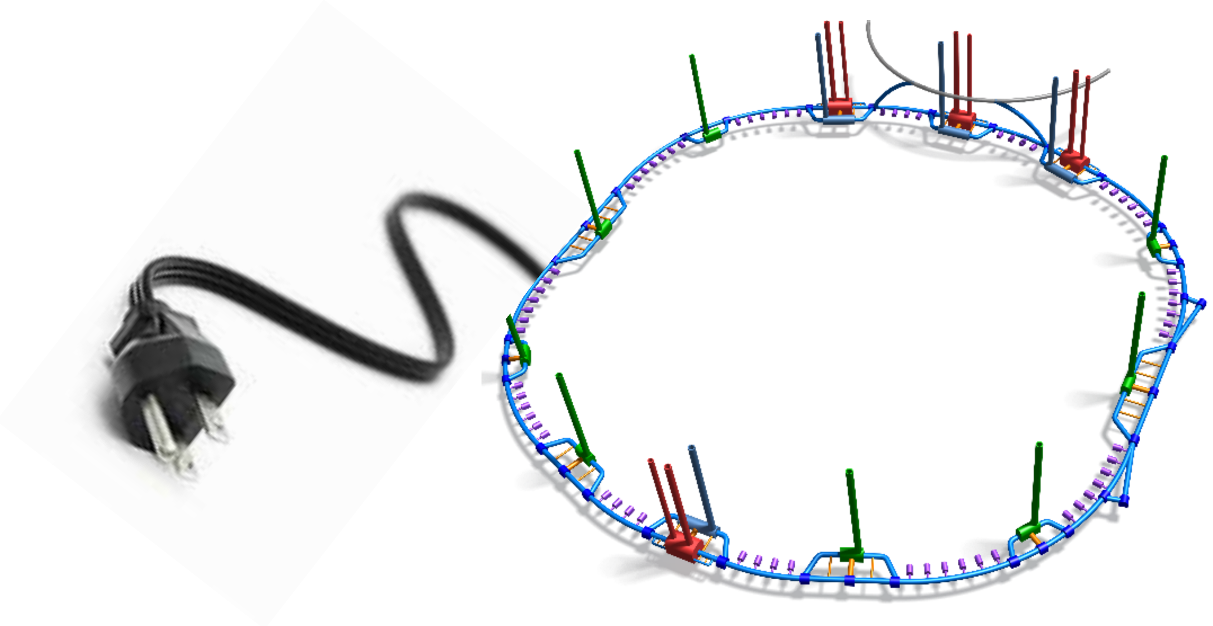
Supply and Distribution of Electrical Energy

FCC week 2017, Berlin

Davide Bozzini - CERN

With the contribution of the FCC Infrastructure & Operation Working Group and CERN Electrical Group members



Outline

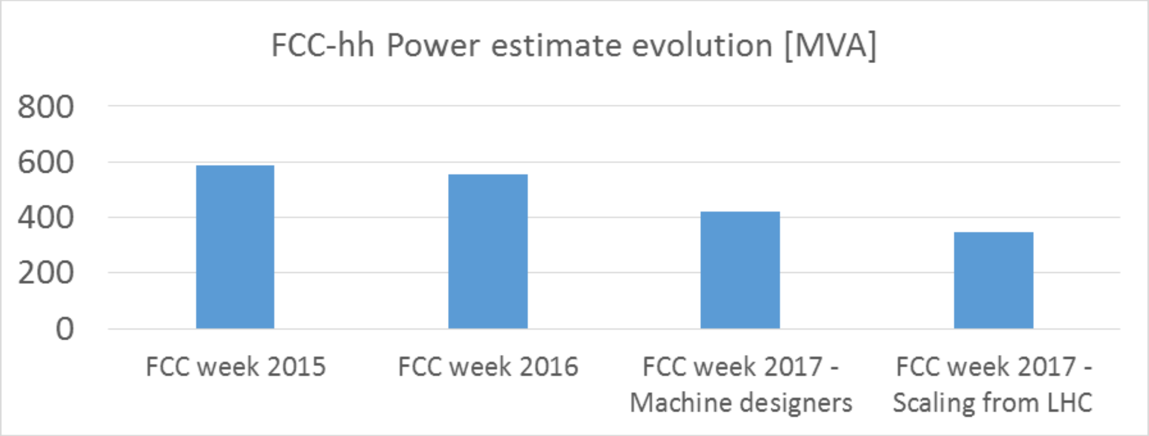
- Power consumption estimate
- Availability of electrical power
- Transmission network
- Distribution network
- Arc electrical infrastructure
- Network quality
- Geneva based related aspects
- Conclusion

Power Consumption Estimate FCC-hh

- **FCC week 2015**
  - First estimate for FCC-hh scaled on **4 x LHC design report** and systems estimate when available
- **FCC week 2016**
  - Definition of **maximum target** power consumption for **FCC-hh at 555 MVA**
- **FCC week 2017**
  - **Two approaches for FCC-hh**
    - Input from machine/ system designers
    - Scaled from LHC real consumption

System	FCC week 2015	FCC week 2016	FCC week 2017	
			Machine designers	Scaling from LHC
FCC-hh	585	555	423	347
Injectors			122	
Data centers			7	

Values expressed in MVA – Considered Power Factor = 0.9



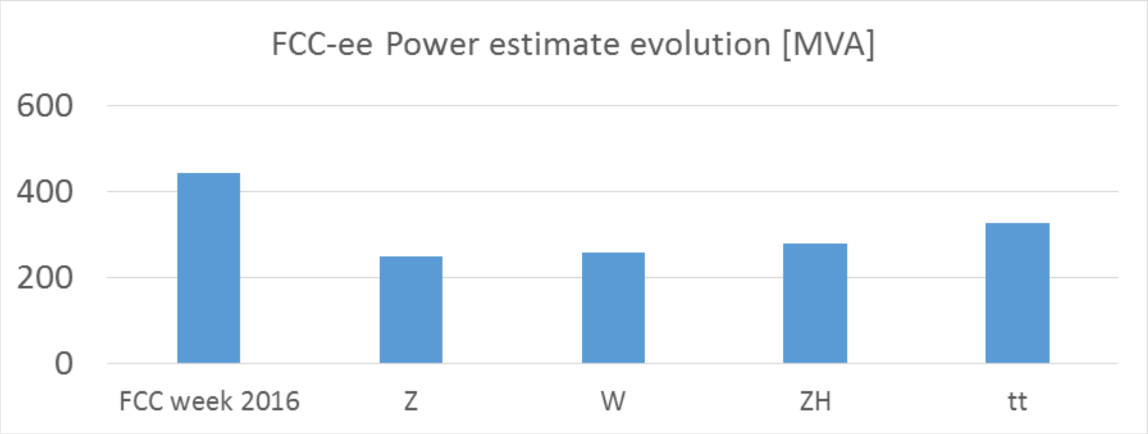
Injectors requirements and data centres not included

Power Consumption Estimate FCC-ee

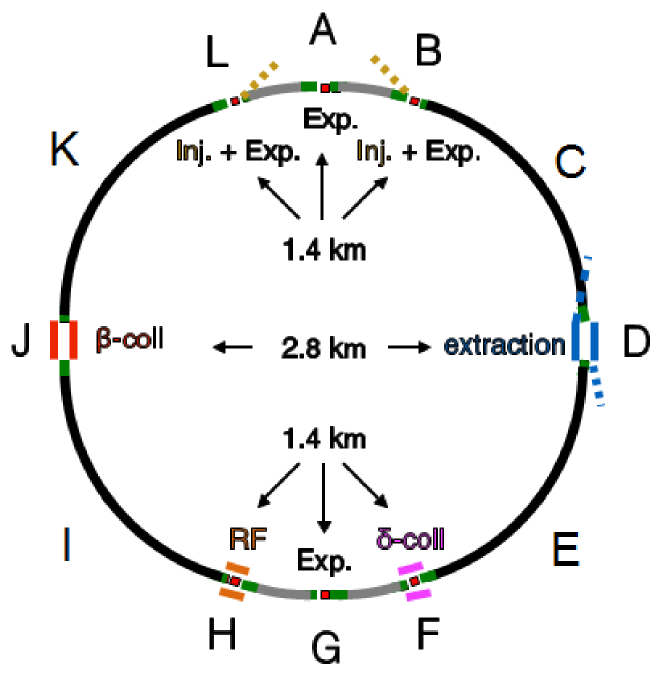
- **FCC week 2015**
  - Not addressed
- **FCC week 2016**
  - Definition of **maximum target** power consumption for **FCC-ee at 444 MVA**
- **FCC week 2017**
  - Input from machine/system designers
  - As summarized in the paper ELECTRICAL POWER BUDGET FOR FCC-ee, F. Zimmermann and al.

lepton collider	Z		W	ZH	$t\bar{t}$	LEP2
luminosity / interaction point [10^{34} cm^{-2}s^{-1}]	207	90	19	5	1.3	0.012
total RF power [MW]	163		163	145	145	42
collider cryogenics [MW]	3	2	5	23	39	18
collider magnets [MW]	3		10	24	50	16
booster RF & cryogenics [MW]	4		4	6	7	N/A
booster magnets [MW]	0		1	2	5	N/A
pre-injector complex [MW]	10		10	10	10	10
physics detectors (2) [MW]	10		10	10	10	9
cooling & ventilation [MW]	47		49	52	62	16
general services [MW]	36		36	36	36	9
total electrical power [MW]	276	~275	~288	~308	~364	~120

Values expressed in MW – Considered Power Factor = 0.9

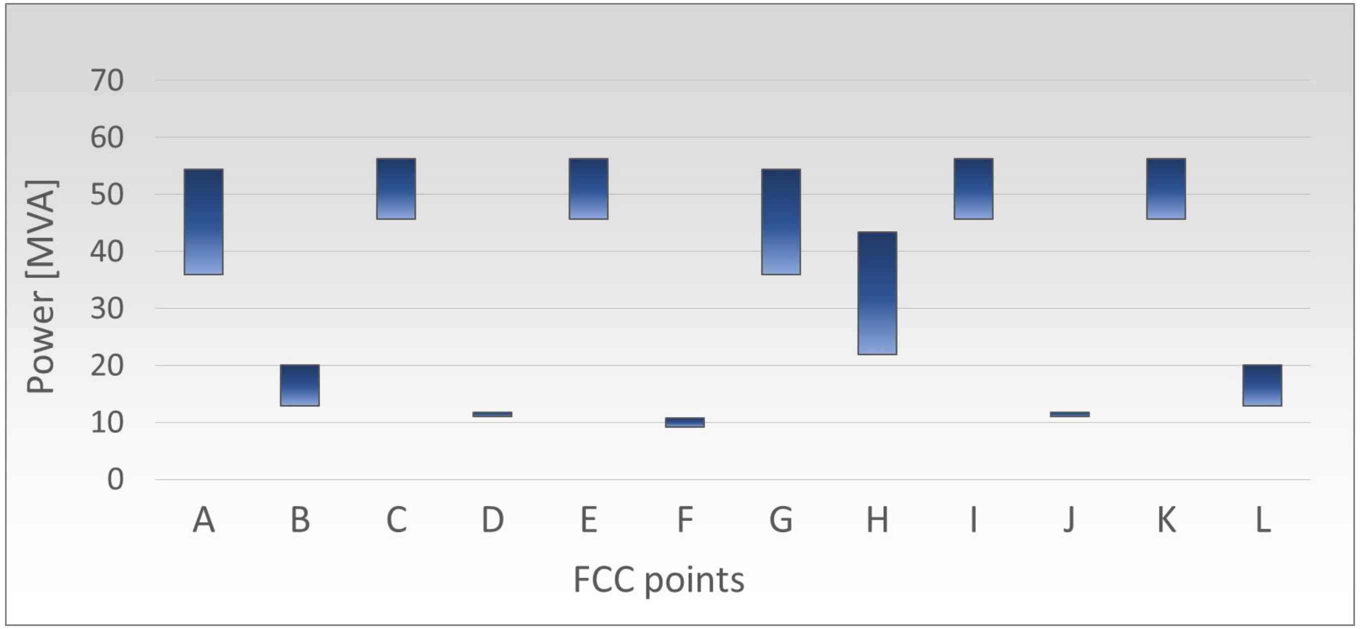


Power Requirements at each FCC-hh Point



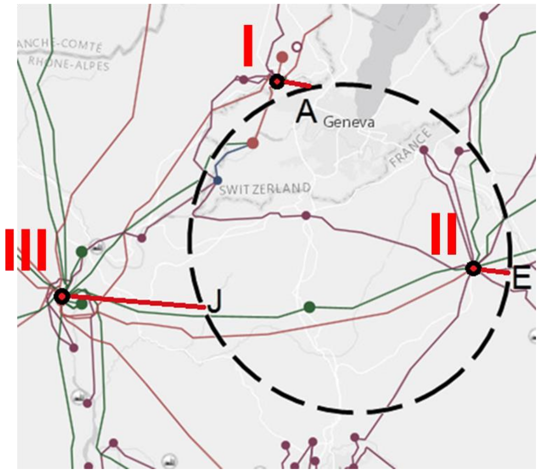
FCC week 2017	
Machine designers	Scaling from LHC
423	347

- Power distribution location according to systems layouts

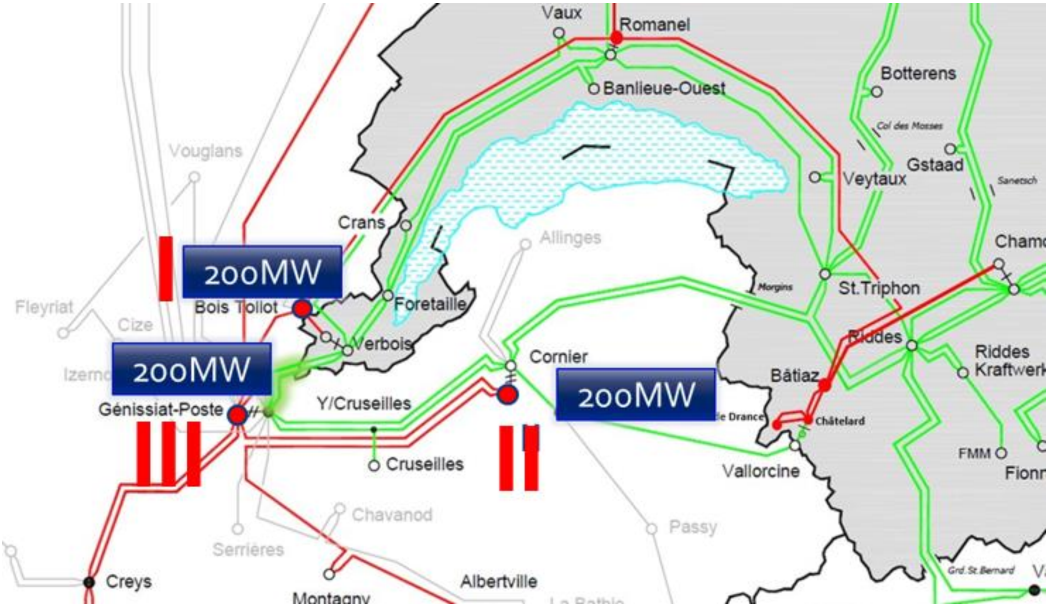


Range of FCC-hh power requirements at each point

Availability of power at European grid level



- Based on mid long term plan (2030) of the network operator
- Additional **200 MW are available** simultaneously at each 400 kV source (I,II, III)
- Total power higher than 600 MW will require **major hardware changes** at the European grid level
- Maximum available power in case of N-1 availability of the sources might **impact the transit of power at grid level**
- Power availability on existing sources operated at lower voltages (230 kV and 132 kV) is **included in the same budget** (3 x 200 MW)



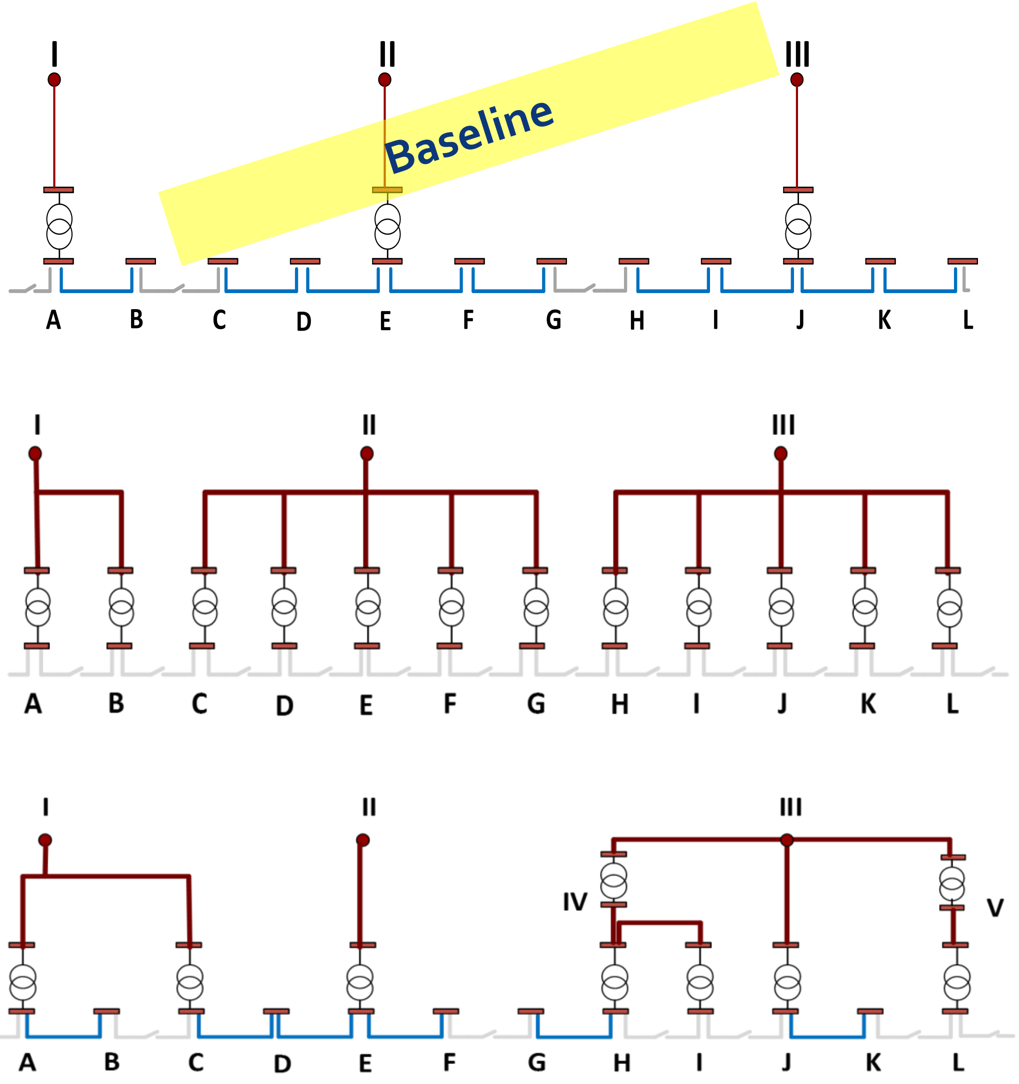
---- 400 kV ---- 230 kV

Transmission Network

- 3 existing 400 kV sources of the European grid connected to 3 incoming 400 kV substations located on the nearest FCC points and a transmission ring linking the 12 substations located at each point

- Radial powering of FCC points from the existing sources. A transmission ring might be necessary for operability and availability purposes

- Optimization by powering zones at different voltage levels with a topologies

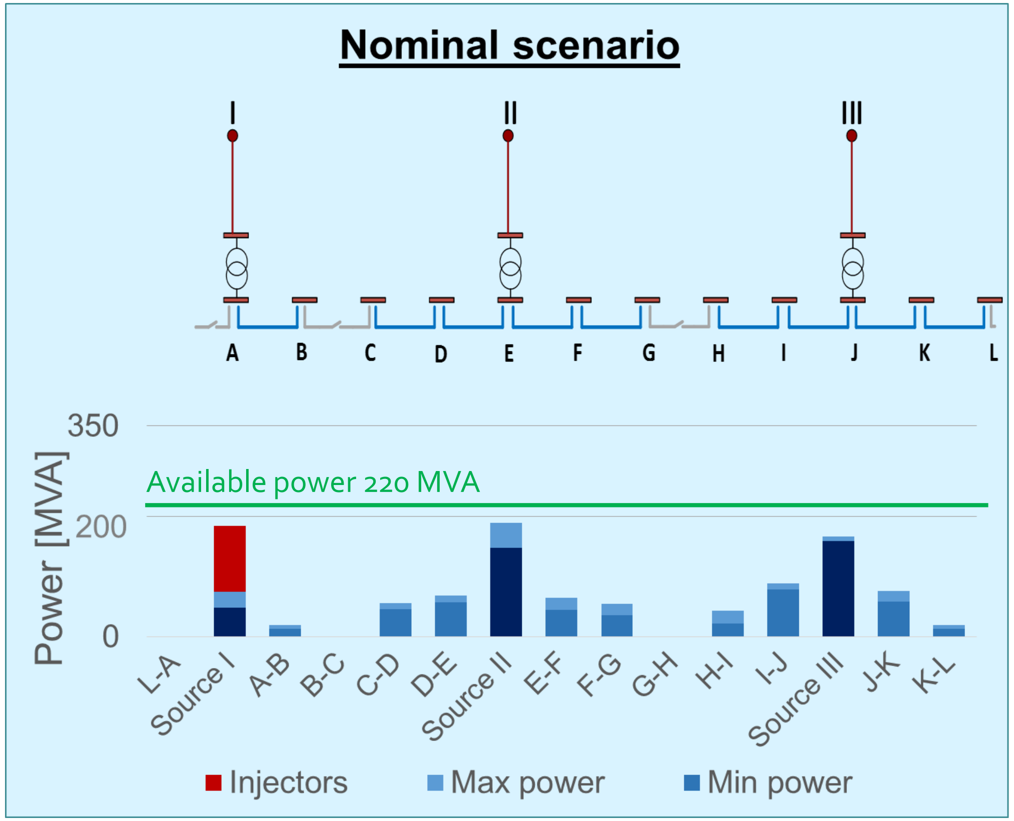


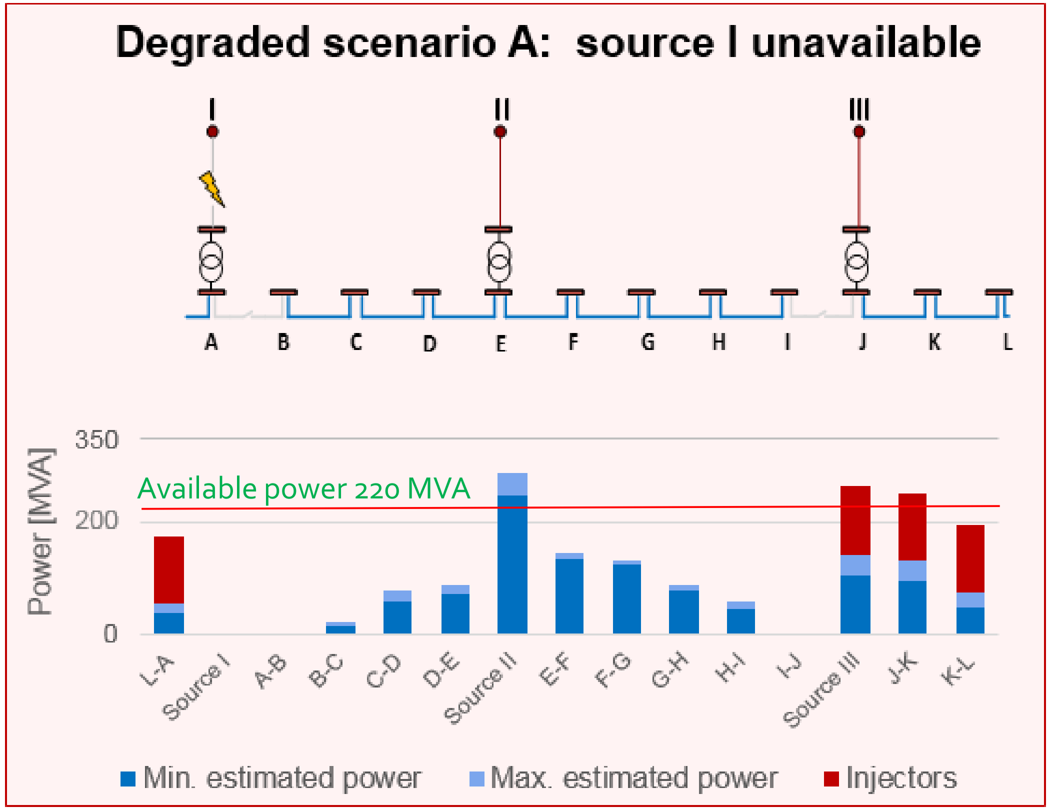
Transmission Network

Operating Modes

- Power required by each source
- Transmitted power between neighbouring points

Degraded scenario is the extreme considering
- Loss of source I supplying the injectors
- FCC-hh kept operational with beam





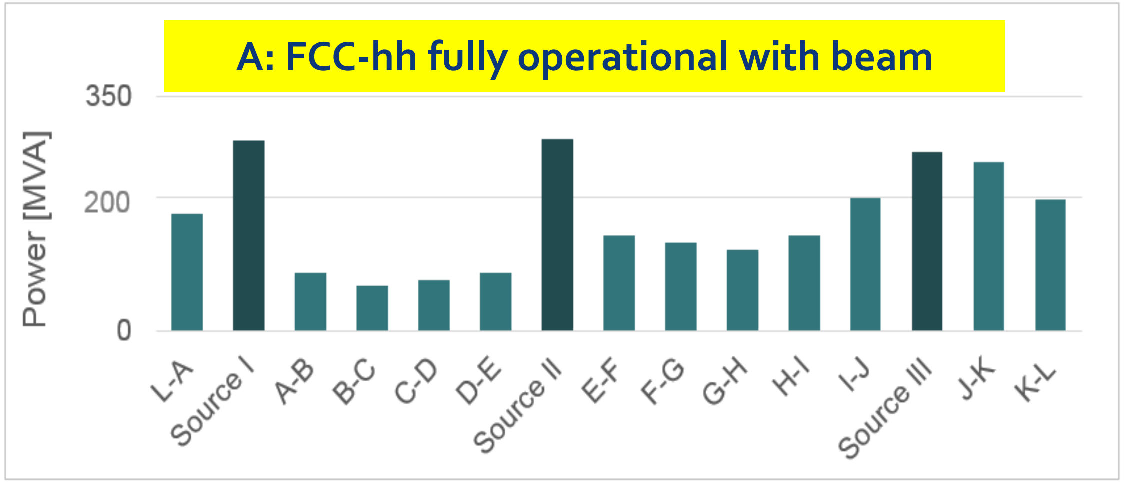
Transmission Network

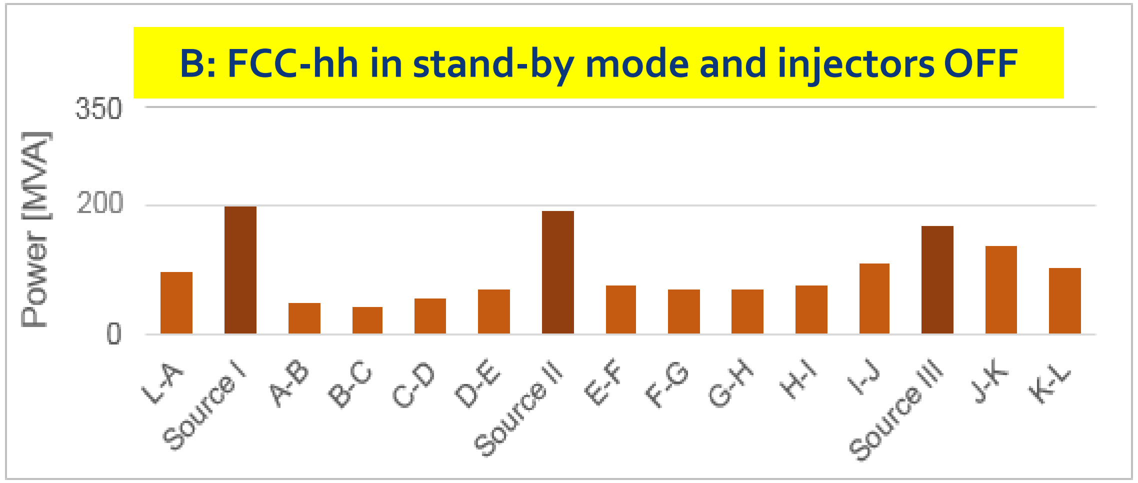
Dimensioning Baseline

- The power loads of the three sources and of each transmission ring segment are calculated for the unavailability of each one of the three sources.
- Maximum value among the three calculated is retained for dimensioning purposes
- The network is reconfigured to equally distribute the power on the two remaining available sources
- **Two machine states are calculated**

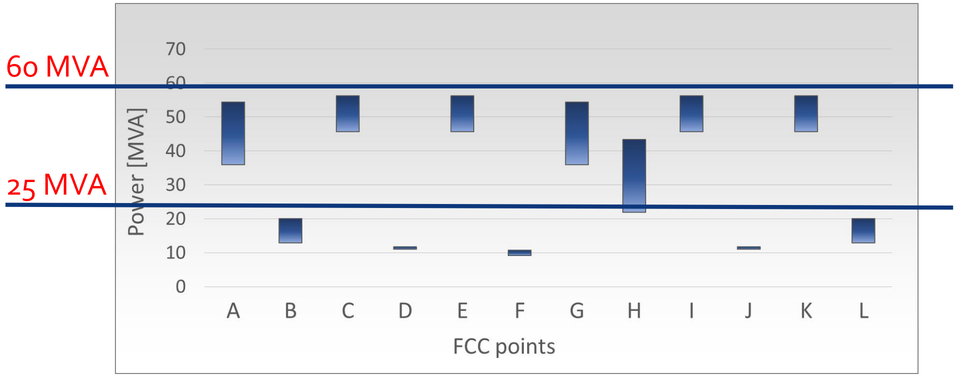
  A: FCC-hh fully operational with beam

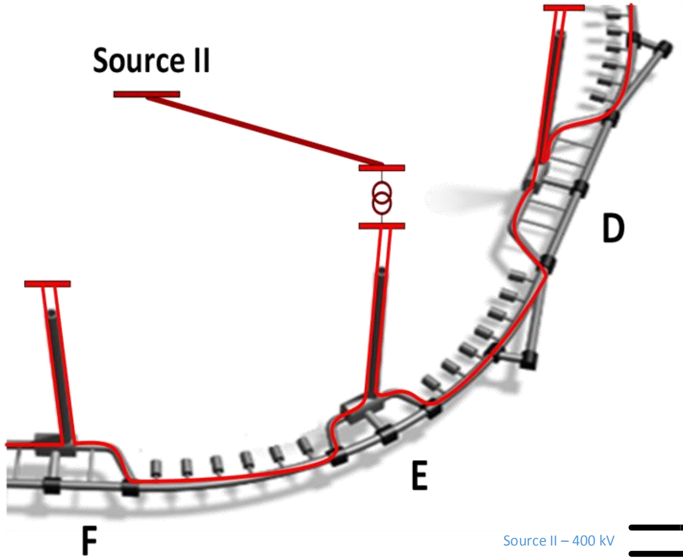
  B: FCC-hh in stand-by mode and injectors OFF

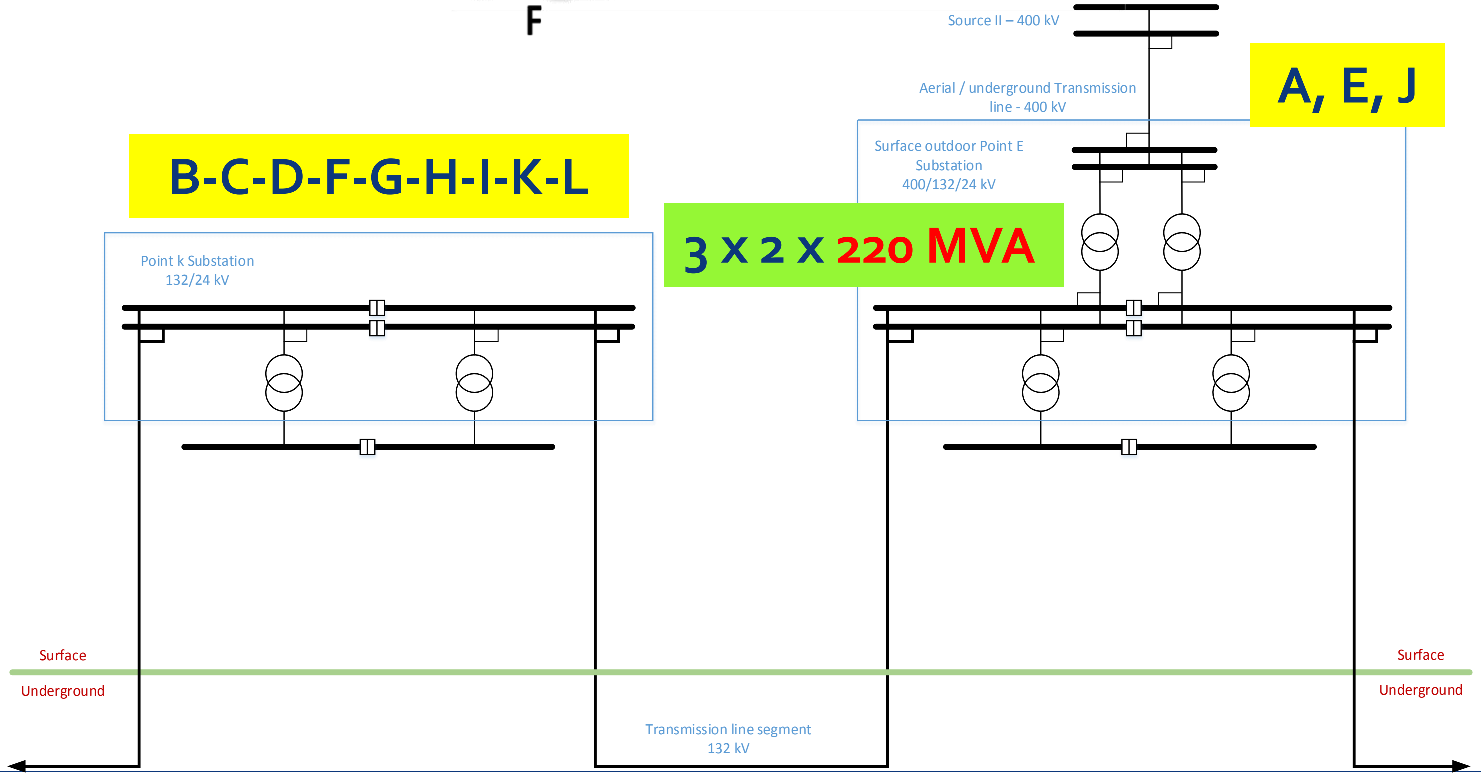




Transmission Network
Substations Dimensioning







7 x 2 x 60 MVA (A-C-E-G-H-I-K)
5 x 2 x 25 MVA (B-D-F-J)

Transmission Network
Installed Power

- Installed power
  - Is determined from **accelerator power requirements** and **network operating modes**
  - Is the input for the infrastructure **dimensioning**
  - Is the input for the infrastructure **cost estimate**
  - Contributes to **power losses**

Losses calculation example:

- Typical transformer **efficiency of 0.98** and considering a **power factor of 0.9** with all transformer loaded at 30-40 % of their nominal power rate
- Transformers losses in nominal configuration are of the order of **30 to 40 MW**
- These losses **shall be included in the total budget**

Point	Power rating [MVA]			Transformers x point	Installed power [MVA]
	220	60	25		
A	2	2	0	4	520
B	0	0	2	2	50
C	0	2	0	2	120
D	0	0	2	2	50
E	2	2	0	4	520
F	0	0	2	2	50
G	0	2	0	2	120
H	0	2	0	2	120
I	0	2	0	2	120
J	2	0	2	4	450
K	0	2	0	2	120
L	0	0	2	2	50
Tot. quantity	6	14	10	30	
Tot. installed Power [MVA]	1320	840	250		**2410**

Distribution Network

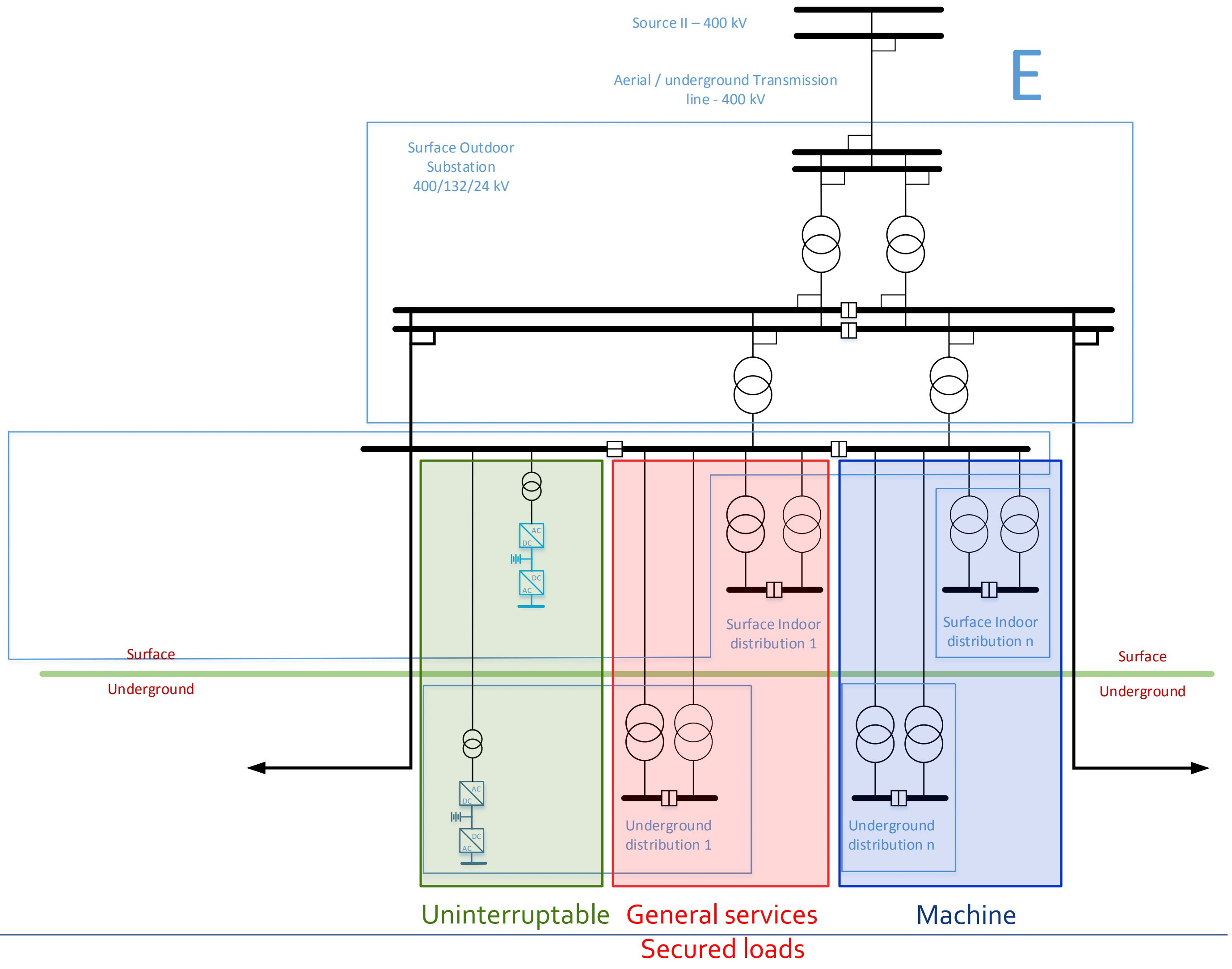
Types of Networks for Accelerators

Type of network	End users voltage level	Loads type	Users individual power range	Unavailability duration (in case of main supply outage)	Topology	Infrastructure complexity
Machine	24 kV 3.3 kV 400 V	Power converters, cooling and ventilation motors, radio frequency	200 W To 1000 kW	Until return of main supply	- Radial supply - Full redundancy	- Passive components - (MV switchgears, transformers, LV switchboards)
General Services	400 V	Lighting, pumps, vacuum, wall plugs	50 W To 200 kW	Until return of main or secondary supply	- MV distribution loop - LV radial supply - Back up sources	- Passive components
Secured	400 V	**Personnel safety** Lighting, pumps, wall plugs, elevators	5 W To 100 kW	10 – 30 seconds	- MV distribution loop - LV radial supply	- Active (diesel engine) and passive components
Uninterruptable	400 V	**Personnel safety** : evacuation and anti-panic lighting, fire-fighting system, oxygen deficiency, evacuation **Machine safety** : sensitive processing and monitoring, beam loss, beam monitoring, machine protection	5 W To 100 kW	None (continuous service)	- MV or LV distribution radial distribution	- Active and passive components - Local energy storage (batteries)

Distribution Network

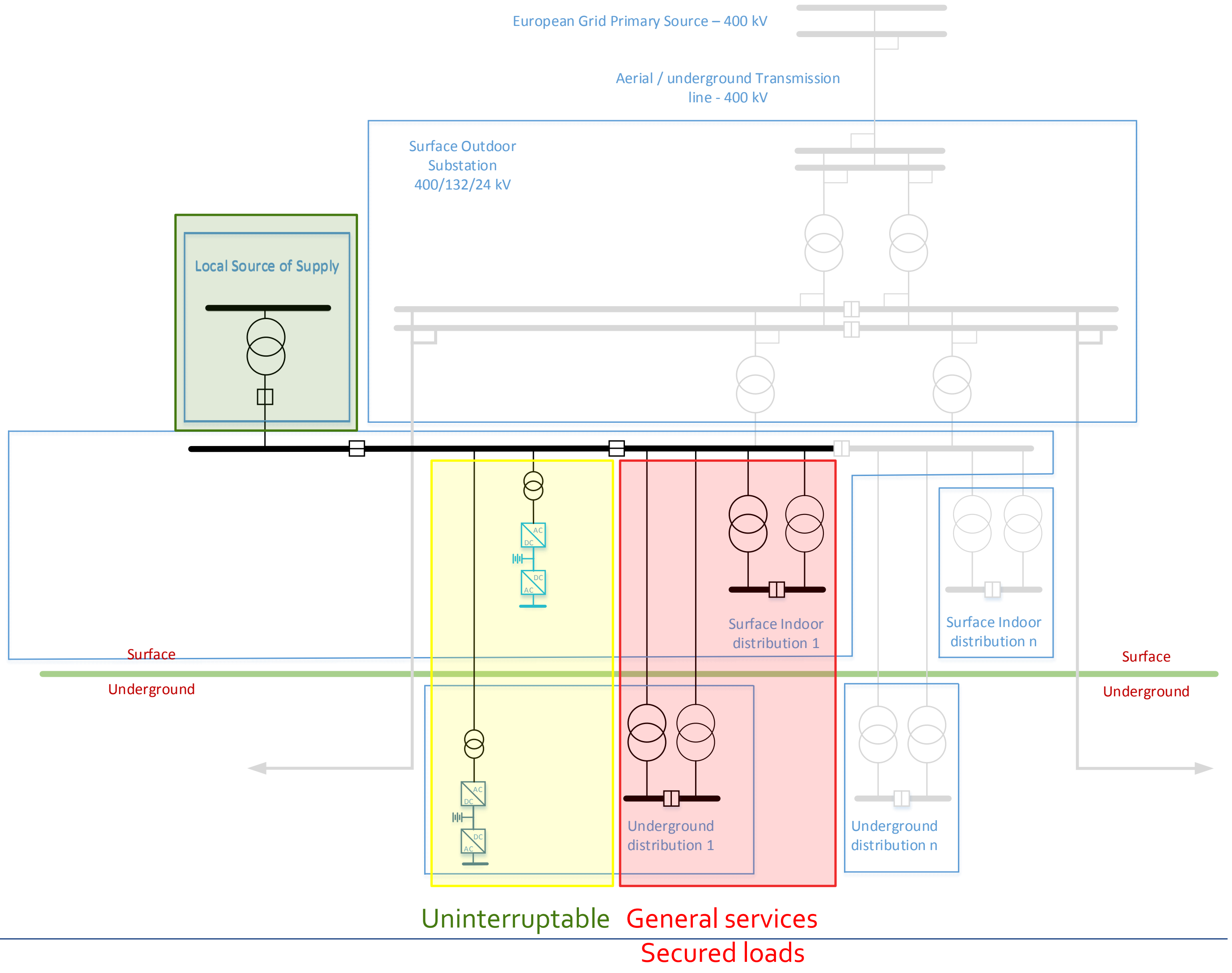
Baseline diagram

- Typical voltage rating **400 V, 3.3 kV up to 36 kV**
- **Indoor** substations
- All distribution networks **supplied by the transmission** network
- **Redundancy** to grant required level of availability, operability and maintainability
- **Secured loads** are part of the general services



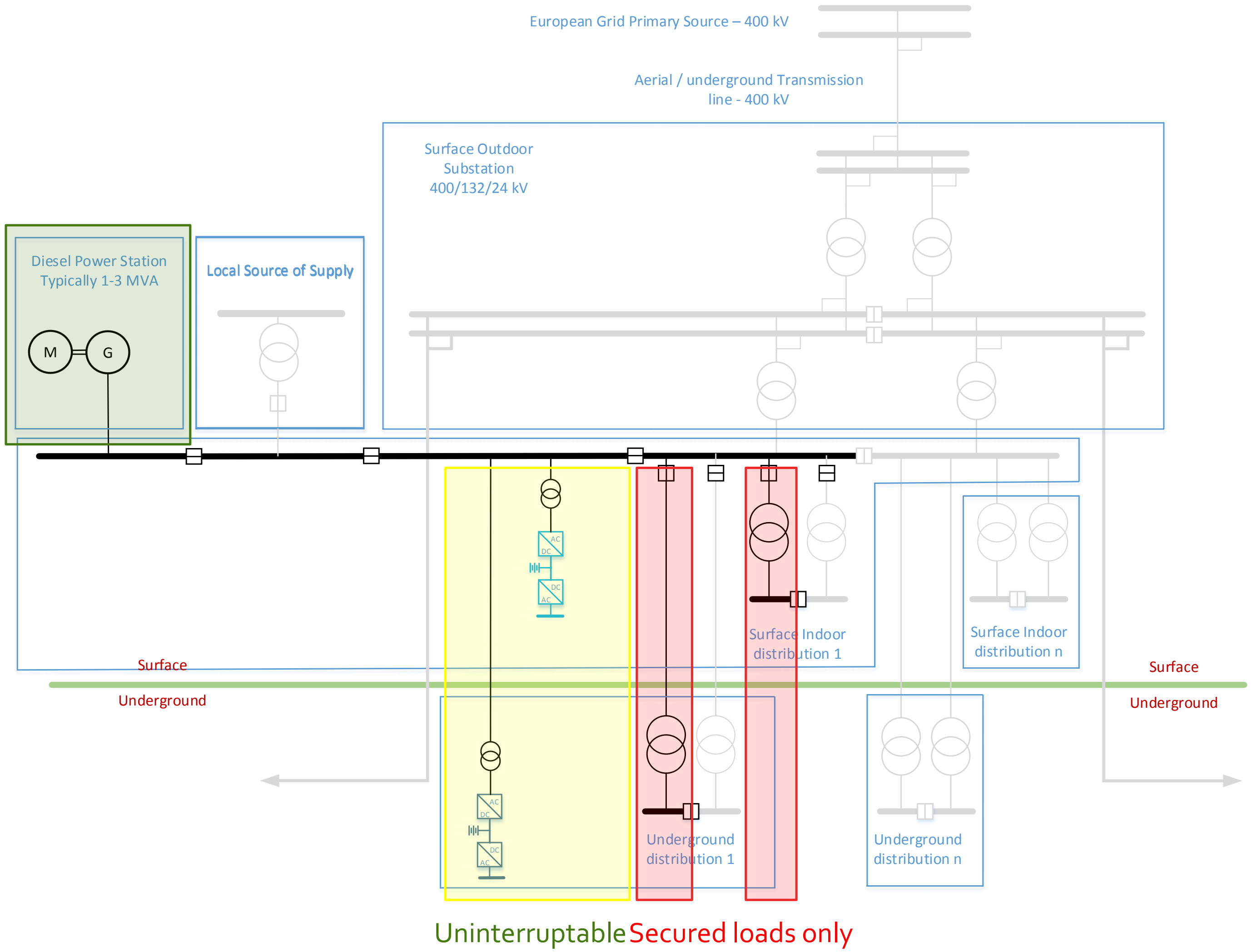
Distribution Network
Second Source of Supply

- **Supplied from local grid** at voltage ratings comprised from 18 kV to 20 kV
- Limited power availability **2 to 5 MW**
- In case of transmission network outage **automatic switch to the second source** supply
- Machine network not supplied
- Commuting time **2 to 5 seconds**



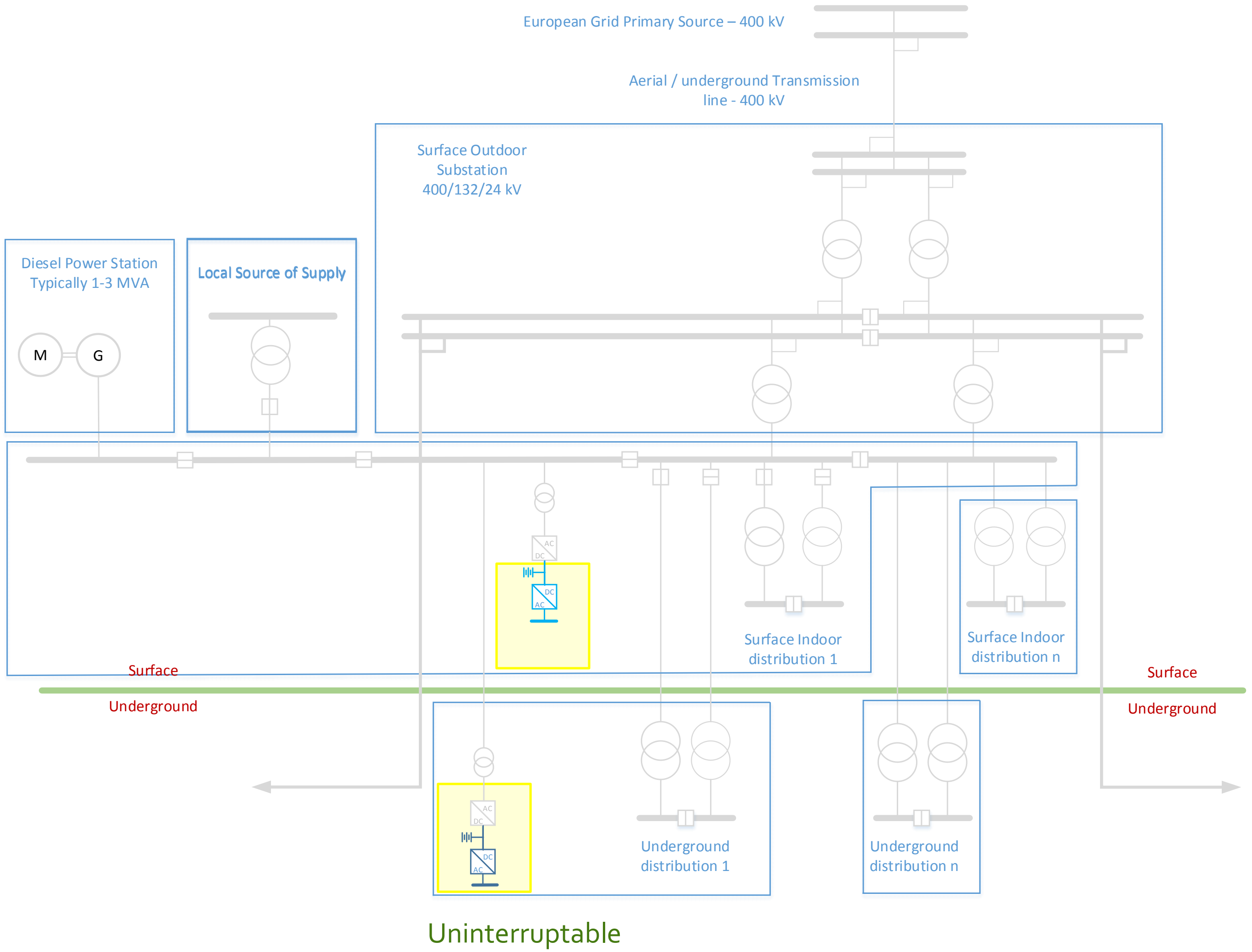
Distribution Network
Third Source of Supply

- **Islanded diesel power stations** connected to distribution network
- Typical power rating **1 to 5 MW**
- In case of transmission network outage and second source unavailability **automatic switch to the third source** of supply
- Machine network not supplied
- General services not supplied
- Commuting time **10 to 30 seconds** corresponding to the start up of the diesel engines



Distribution Network
Uninterruptable Power Supply

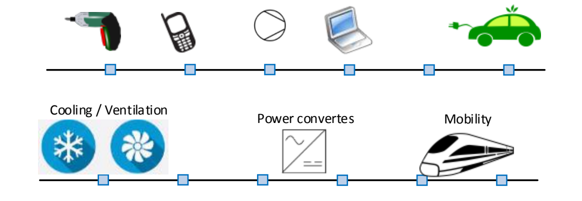
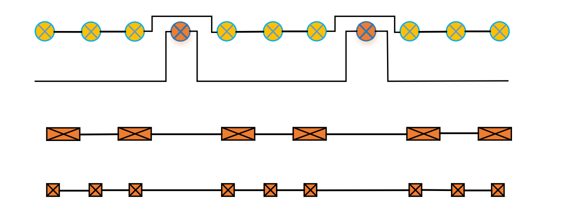
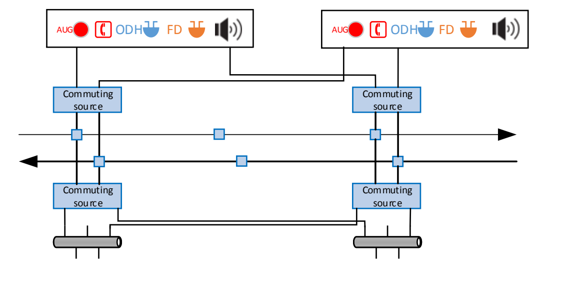
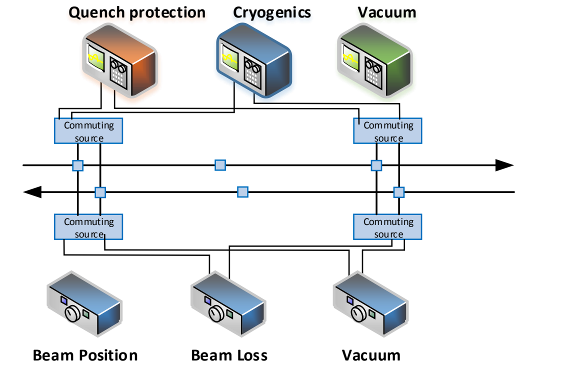
- Supply of **uninterruptable loads only**
- Power rating from **50 kW up to 2 MW**
- In case of transmission network outage, second and third sources unavailability **loads remains supplied** thanks to battery stored energy
- Availability depends from **required autonomy** typically ranging **from 10 min to 2 hours**
- Autonomy is proportional to stored energy (quantity of batteries)



Arc Electrical Infrastructure

Users and Systems

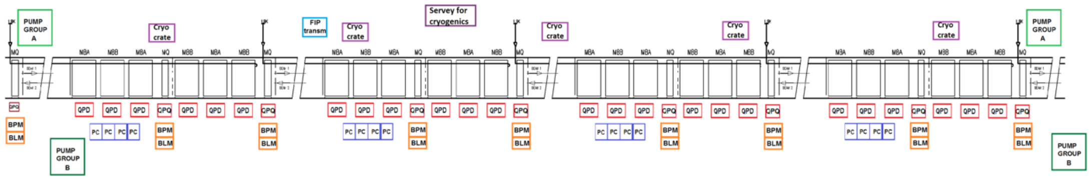
- Loads homogeneously distributed over more than **9 km** of continuous tunnel
- End users supplied at low voltage **400 V ac**
- **Three types of network** required:
  - General services
  - Secured
  - Uninterruptable
- **Critical systems** related to:
  - Personal safety
  - Machine safety
- Critical systems requiring **uninterrupted double redundant supply**

Users	Network type	Schematic layout
Generic power sockets Users power sockets	General Services Secured	
Controlled lightning Permanent lightning Evacuation lightning Antipanic lightning	General Services Secured Uninterruptable Uninterruptable	
Safety systems Communication / Star points	Uninterruptable Double redopundancy	
Machine Protection Beam protection	Uninterruptable Double redopundancy	

Arc Electrical Infrastructure

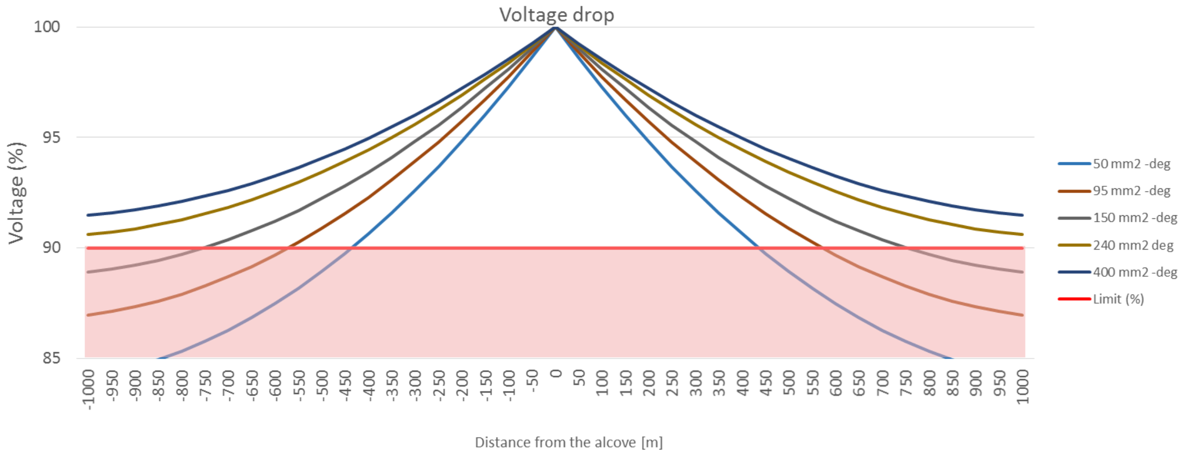
Requirements

- Maximum 400 V ac linear distribution distance from transformer is **750 m** and depends on:
  - Homogeneous distribution of loads
  - Maximum acceptable voltage drop at the end of radial distribution
  - Efficient protection and selectivity coordination to efficiently handle electrical faults
  - Acceptable cross-section vs. cost ratio of copper/aluminium cables



Load	FCC-hh Arc power consumption estimate* [kW]	
	1 km	**1 alcove**
General services	26.17	27.08
Uninterrupted	8.25	3.63
Secured	1.80	5.99
Power transformers		2.08
Total	**36.22**	**38.78**

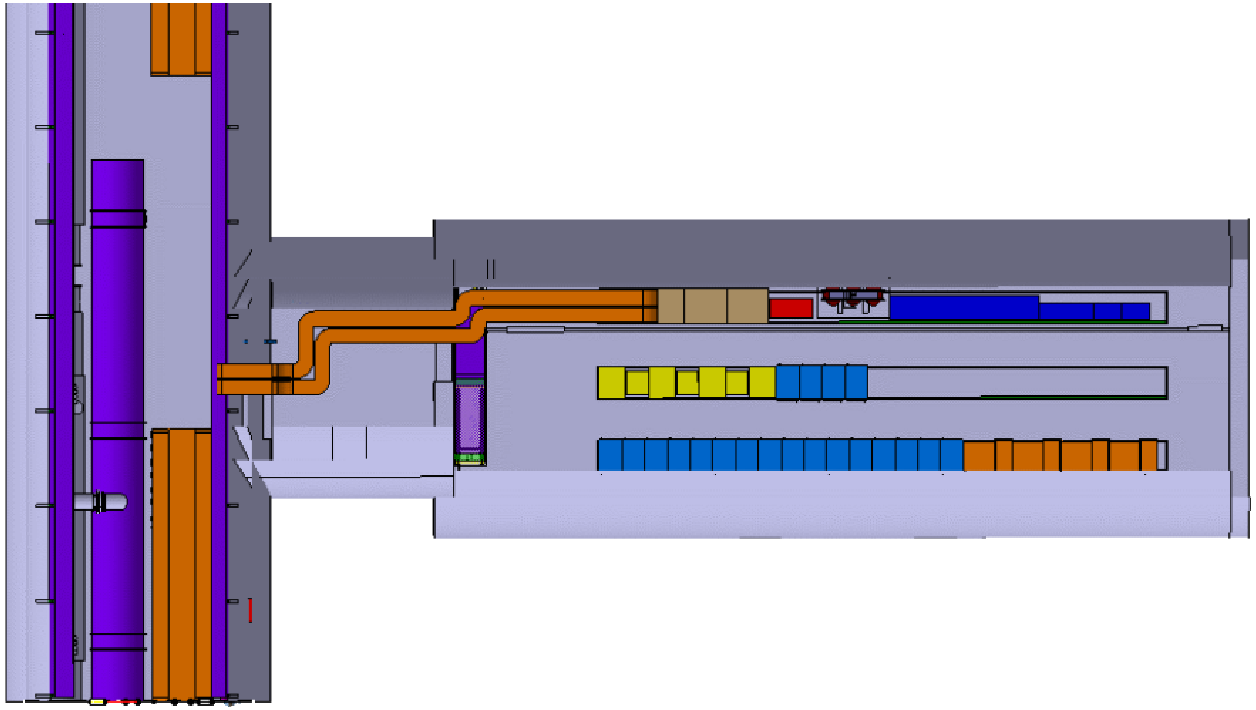
* Calculated from LHC real consumption and scaled to FCC-hh

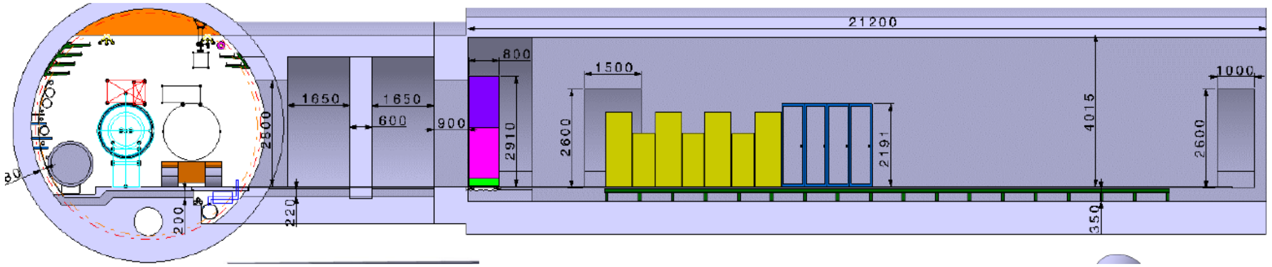


Arc Electrical Infrastructure

Alcoves Requirements

- Located **in the arc every 1500** m for the installation of:
  - Electrical infrastructure equipment
  - Users systems and equipment
  - Systems concentrators such as fire detection, emergency stop,
  - Electronic equipment sensitive to tunnel radiation levels
  - Optical fibre patch panels
- Compartmented area with dedicated **ventilation infrastructure**



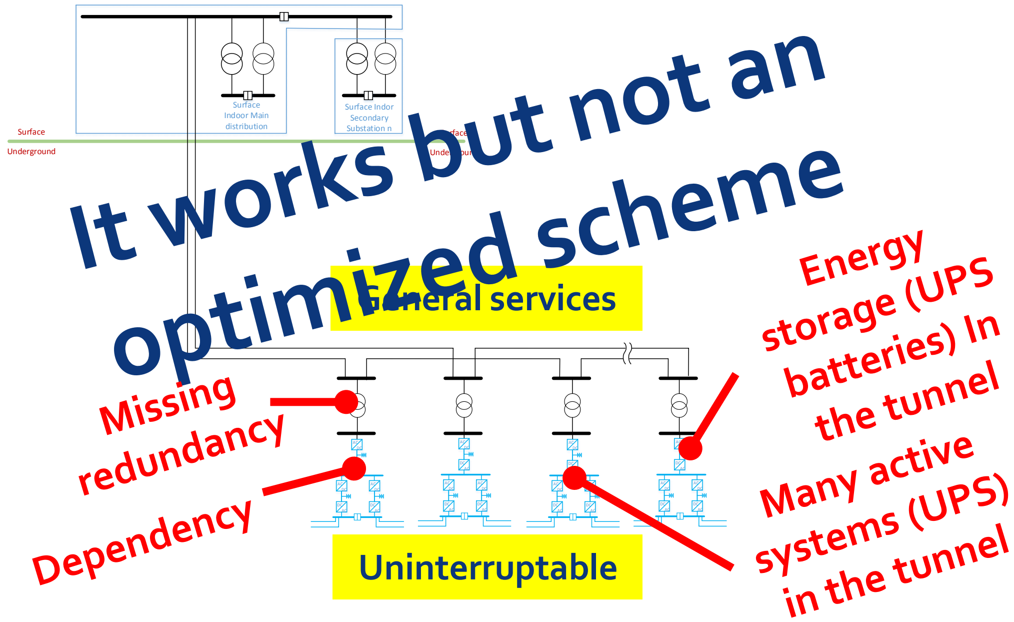


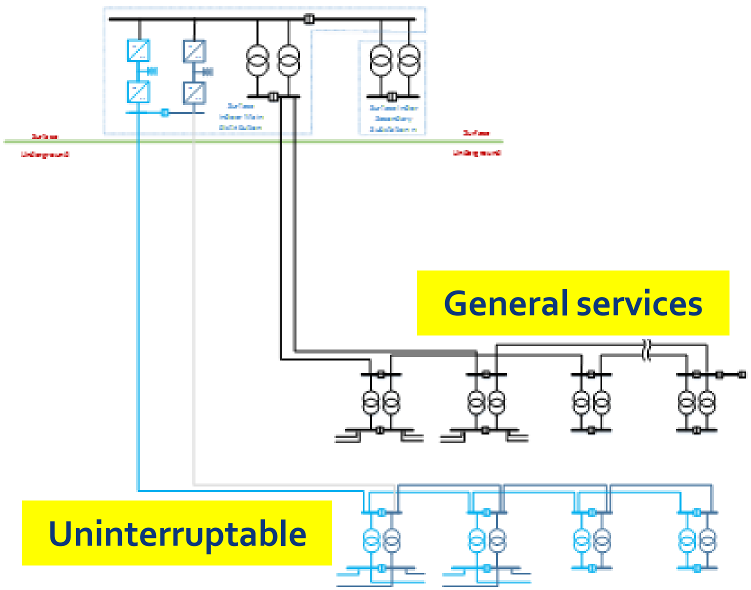
Arc Electrical Infrastructure

RAMS Aspects

Non exhaustive list of characteristics to consider at conceptual design phase concerning the arc distribution

- Separate functionalities - **R**
- Redundancy at all voltage levels and at equipment / systems levels – **M**
- Centralize functionalities - **M**
- Avoid tunnel installation of active systems - **M**
- Avoid energy storage elements in tunnel - **S**

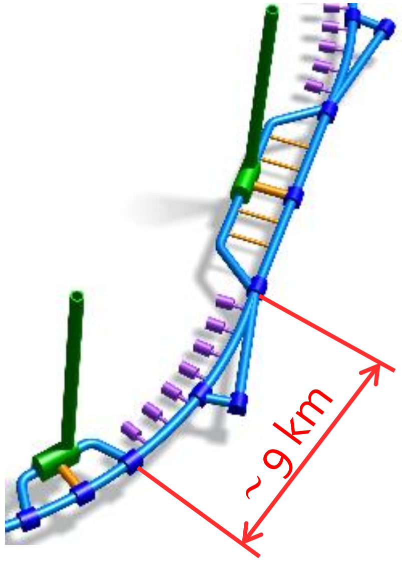


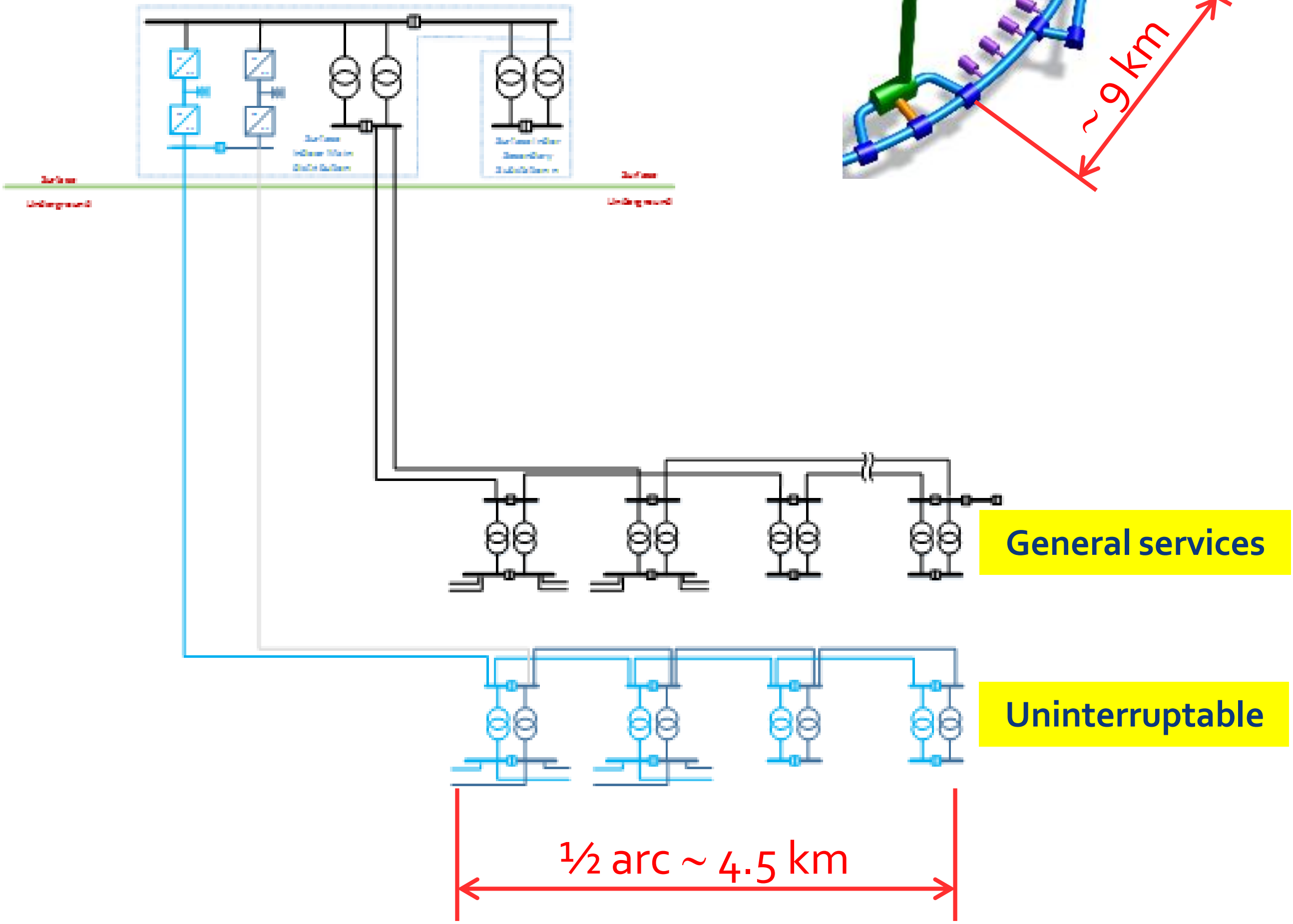


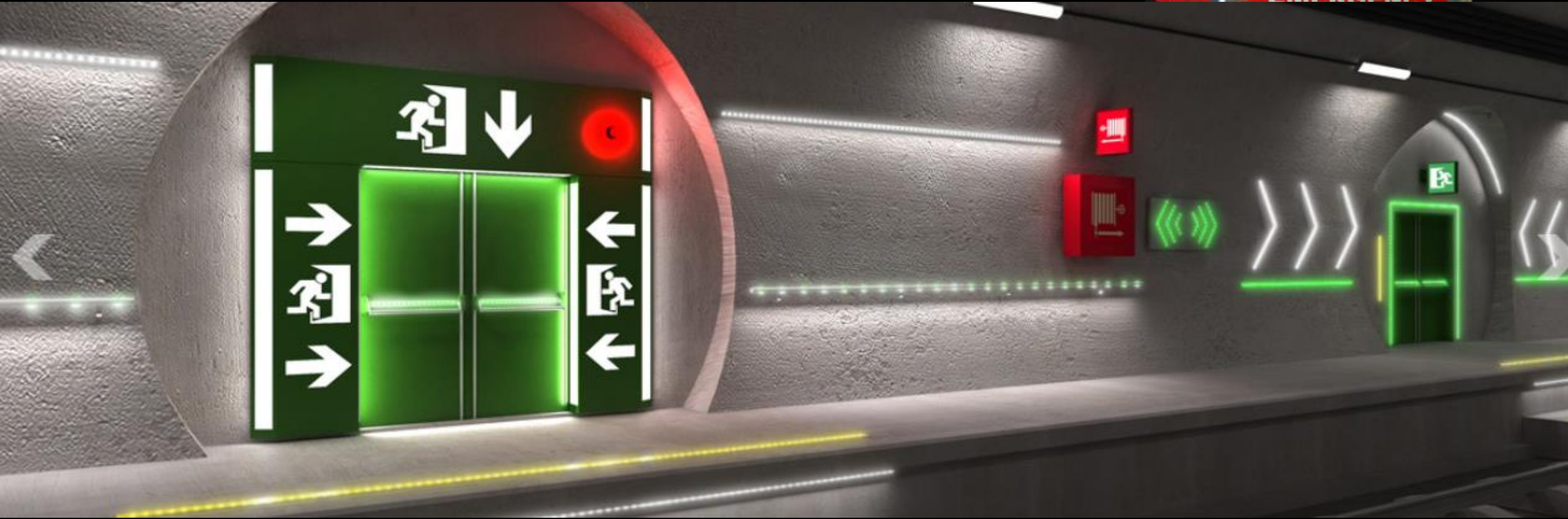
Arc Electrical Infrastructure

High Voltage Distribution Topology

- One general services and one uninterruptable **high voltage network deserving from surface the alcoves** in the arc.
- The general services network is operated in **closed loop mode**.
- The uninterrupted network is structured with a **double redundancy scheme**.
- High-to-low voltage transformer scheme located in each alcove will generate **redundant** general services and uninterrupted low voltage networks





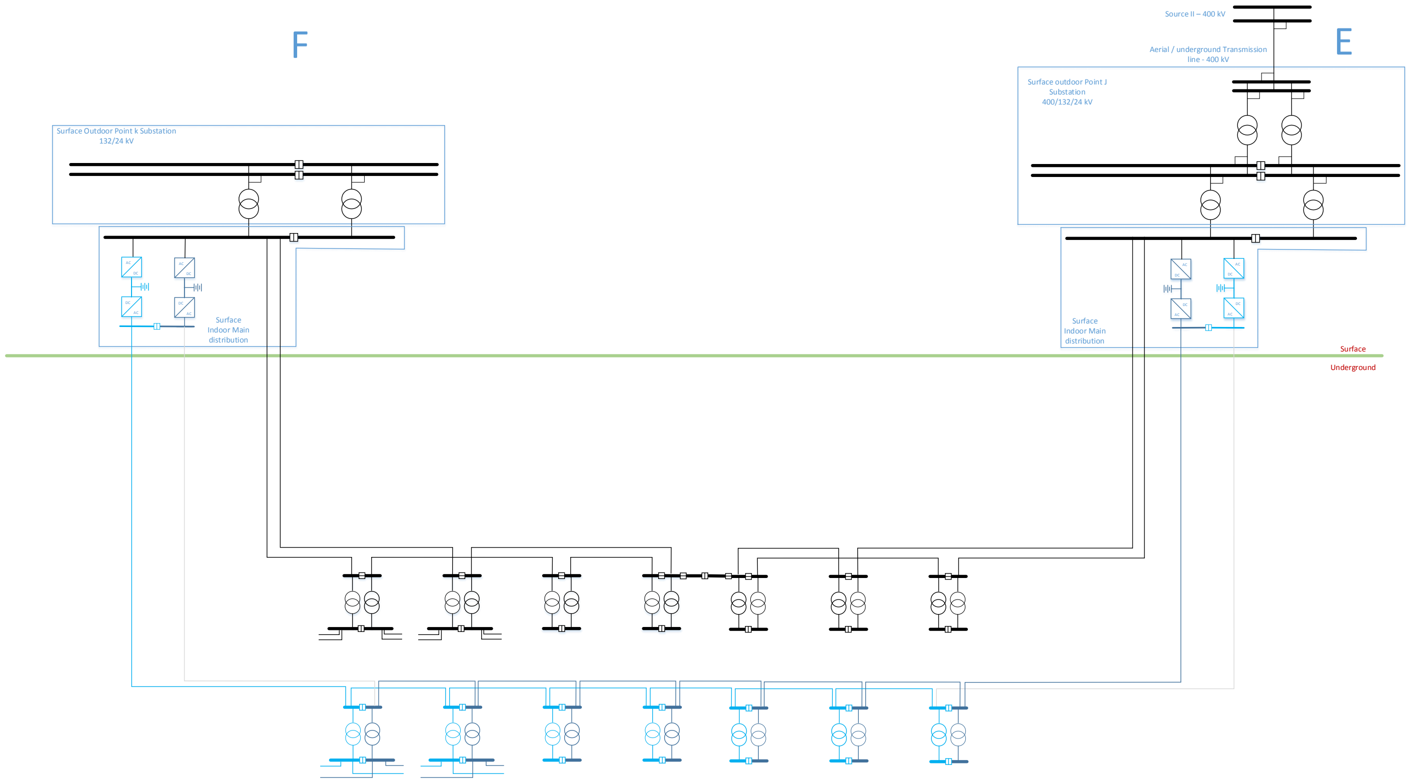

NEMA 3R RAINTIGHT
EMERGENCY


Arc Electrical Distribution

Baseline Scheme

- **General services**
  - Two loops from two neighbouring points covering each half arc
  - Coupling between loops in the middle of the arc for degraded mode operation
  - Might require end of loop voltage compensation

- **Uninterruptible**
  - Double redundant scheme
  - Full arc feed from both neighbouring points
  - No active equipment and energy storage in the alcoves

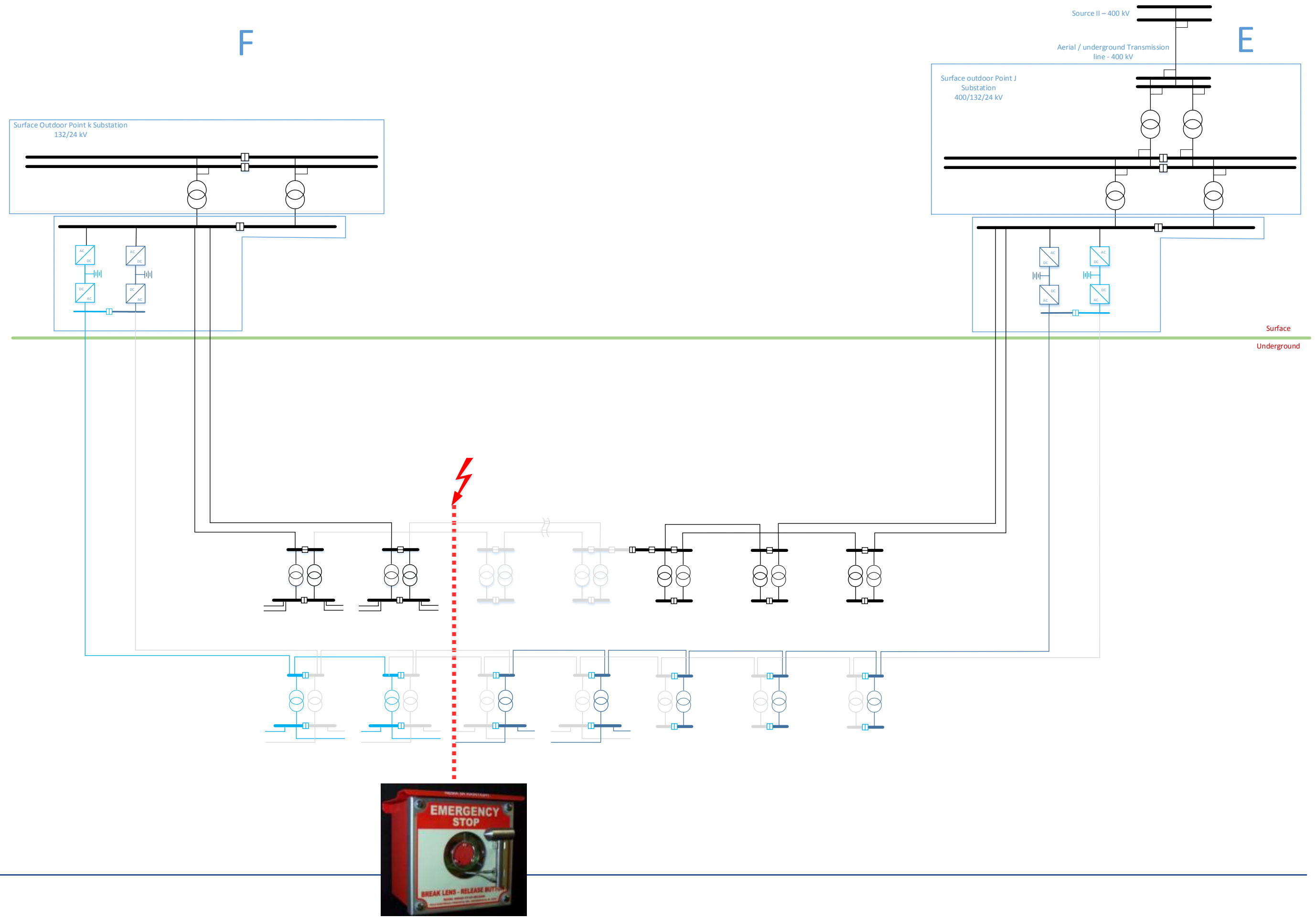


Arc Electrical Distribution

Network availability Example: Emergency Stop Trip in The Tunnel

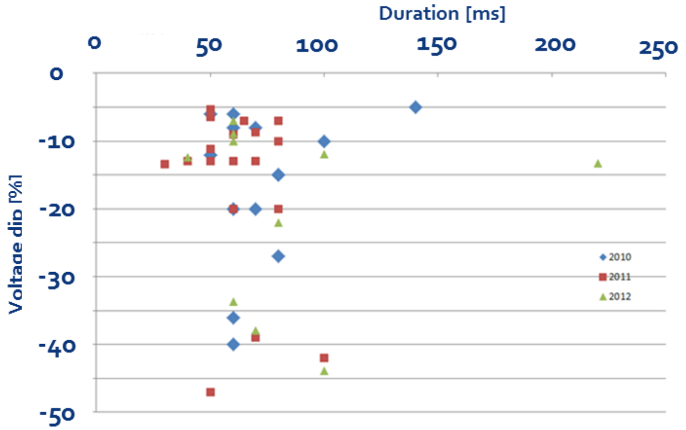
- **General services**
  - The concerned loop segments are opened
  - Non concerned areas remains supplied

- **Uninterruptible**
  - One out of the two redundant supplies remains always available and energized from the two adjacent alcoves

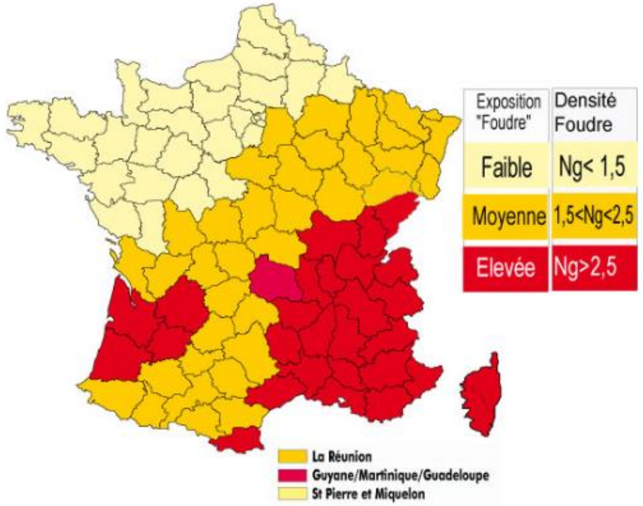


Network Quality

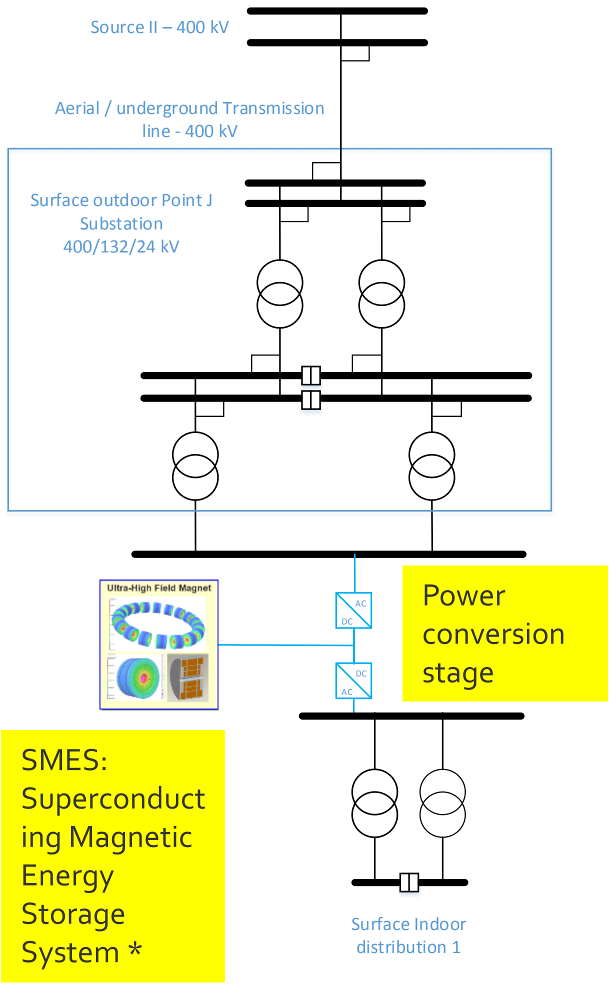
- The quality of the power for FCC may be affected by external causes
  - Harmonics generated **by power transformers energization** on the European grid
  - Voltage drops due to faults on the grid, drops mainly due to **lightning density** in the neighboring area (300 km radius)



Network perturbations



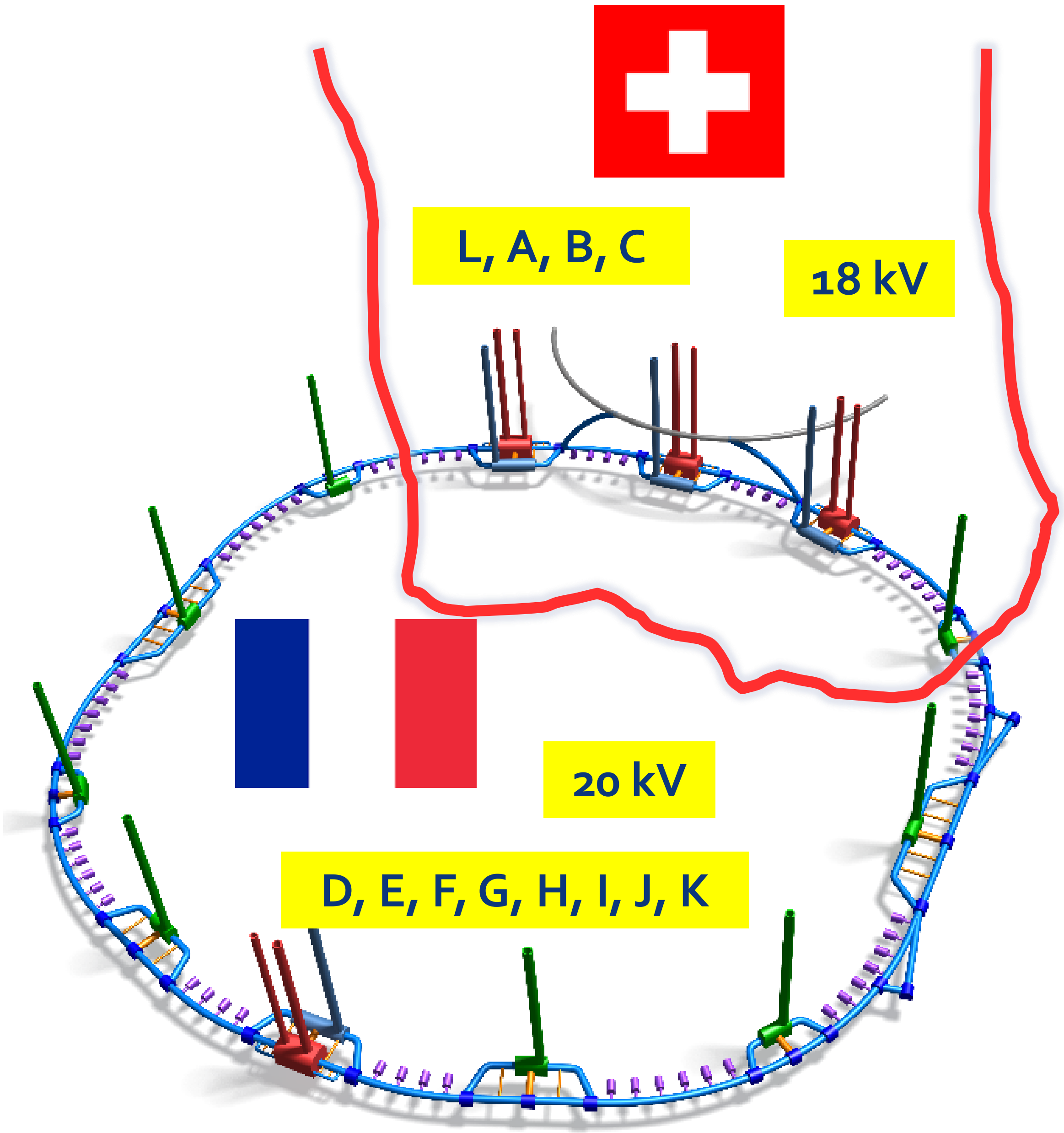
Ng : nr. of lightning/km^2/year



* Image of SMES: Courtesy of Brookeaven Lab, as Presented at theTenth EPRI Superconductivity Conferen ce, Tallahassee, FL, Oct. 12, 2011

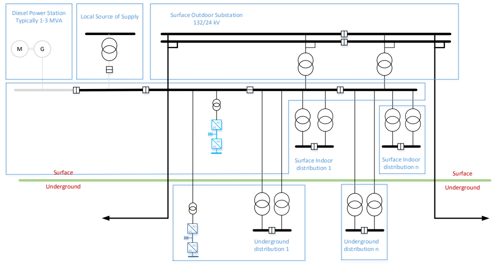
Geneva Based Related Aspects

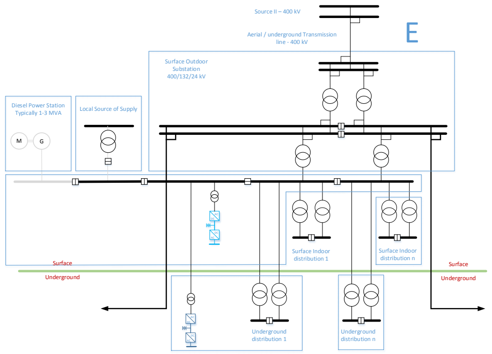
- Current civil engineering baseline includes **4 access points on Swiss and 8 access points on French** territory
- The three **main sources are located in France**
- Swiss and French local (second) sources are **operated respectively at the following different voltage** levels 18 kV and20 kV
- Access points are located in **urbanised and agricultural areas**



Space Requirements

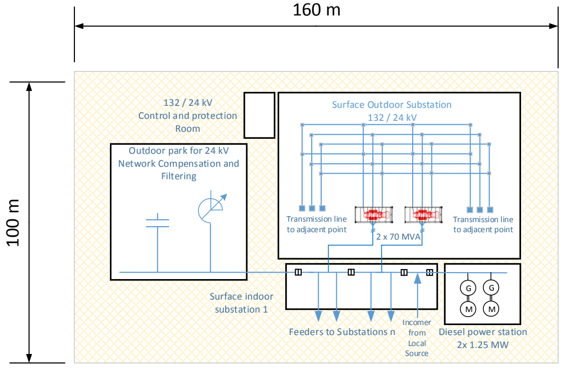
Outdoor / Indoor Substations

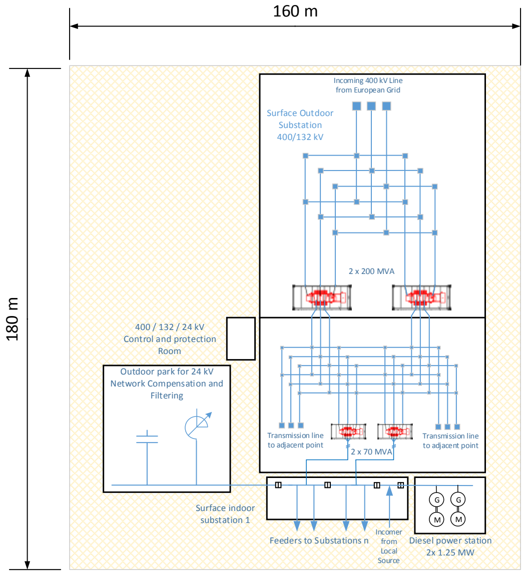




B-C-D-F-G-H-I-K-L

A, E, J





400 kV Air insulated

400 kV Gas insulated

400 kV Oil insulated type transformer

145 kV Dry type transformers

Conclusions

With respect to the CDR …

- Powering of the FCC-hh and FCC-ee from the European grid - **Feasible**
- Baseline transmission and distribution layout for FCC-hh - **Available**
- Functional concept for the electrical distribution in the arcs for the FCC-hh - **Available**
- The same exercise for FCC-ee and HE-LHC – **To be initiated**
- Inputs for an FCC-hh electrical infrastructure cost and schedule review based on the proposed baseline - **Available**

… and from a conceptual design study point of view

- Comparative study for the transmission line between points - **To be completed**
- Power consumption estimates and location - **To be continued**

Thank you for your attention

CERN | EN ENGINEERING DEPARTMENT