Design considerations for the FCC electrical network architecture

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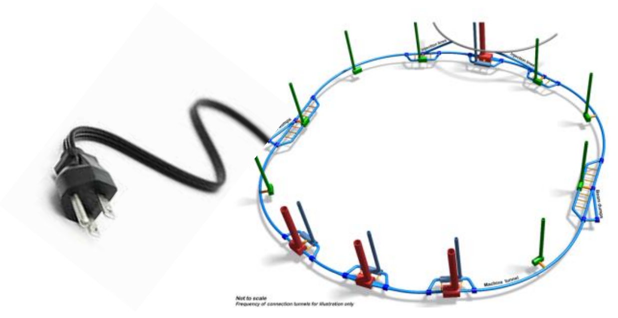
With the contribution of the FCC Infrastructure & Operation Working Group and CERN Electrical Group members



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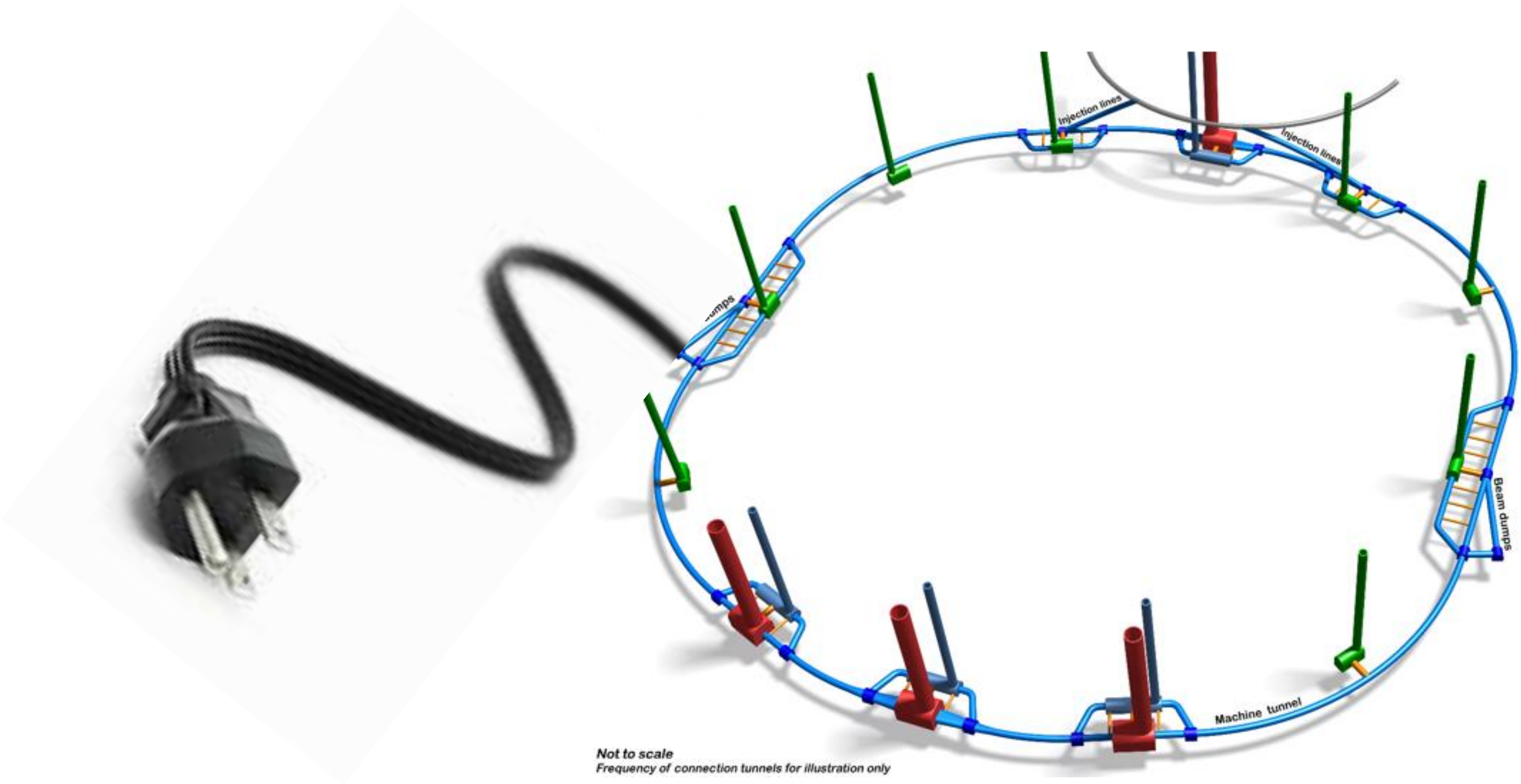
Setting the scene



Powering a 100 km underground accelerator

Inputs for the design study

- Targeted maximum power requirements: 400 MW (FCC-ee) and 500 MW (FCC-hh)
- End users and systems distributed over a length of 100 km on surface and underground
- Site-specific in Geneva area, linked to CERN accelerator complex

Objectives

- Bring power from transmission network to end users and systems
- Maximise availability, reliability, operability and maintainability
- Maximise load capacity
- Minimise power losses
- Minimise environmental impact
- Minimise safety risks

Typology of electrical networks for the accelerator

Power source

Hydro, nuclear power plants

Transmission network

European grid

Regional grid

Distribution network

Machine network

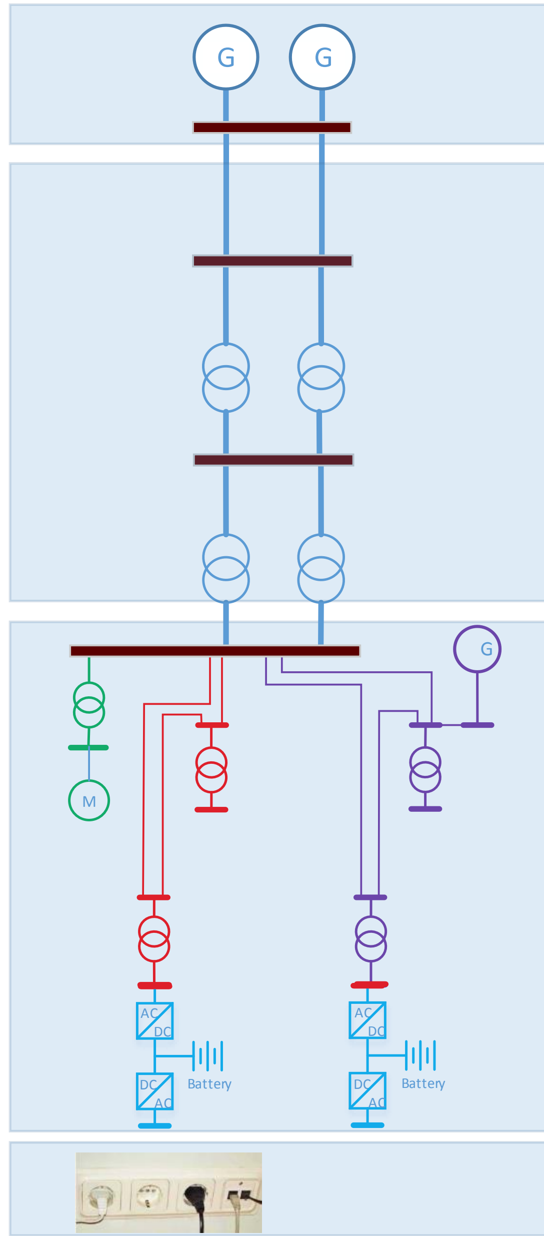
General services

Secured network

Uninterrupted network

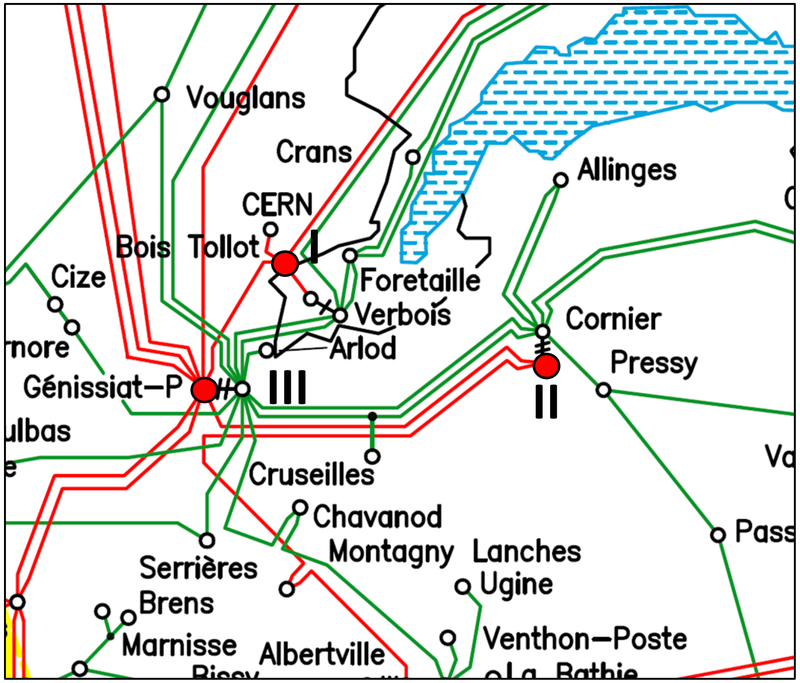
Wall plug distribution

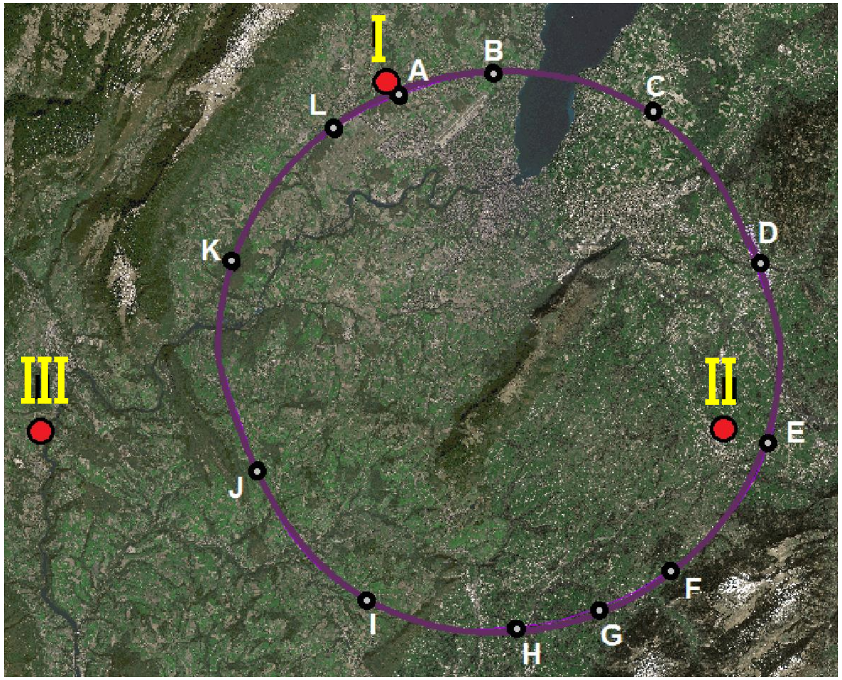
End users



Available sources for the electrical power

- Three 400 kV transmission substations are available
- Redundancy of transmission lines done at the level of European grid
- Power to be transmitted to the nearest FFC access point



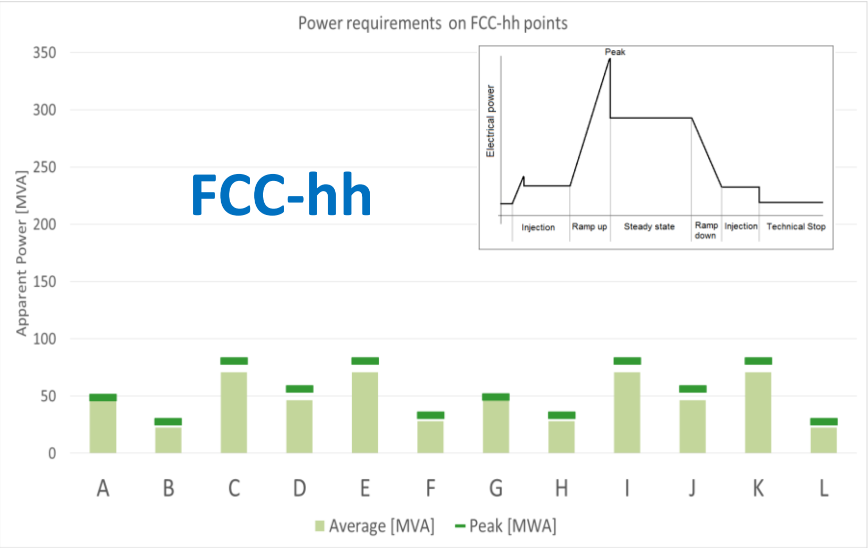


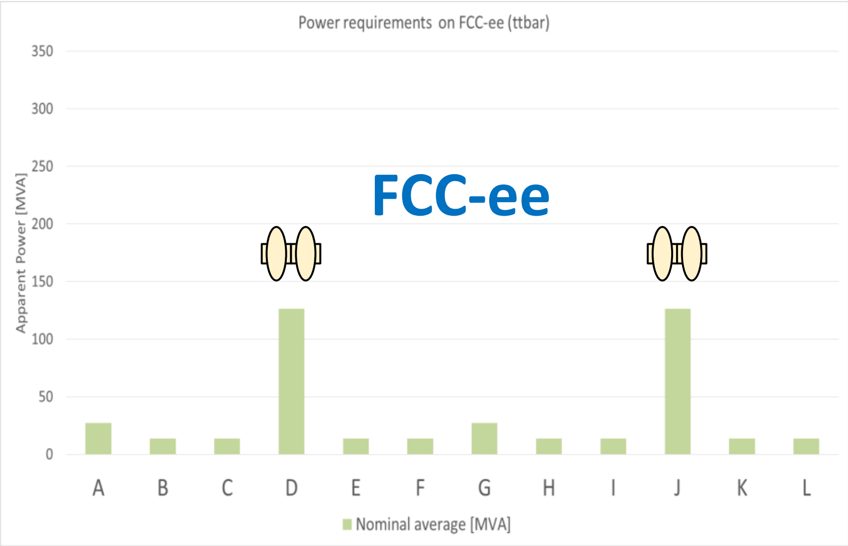
---- 400 kV
---- 230 kV

FCC-hh and FCC-ee power requirements

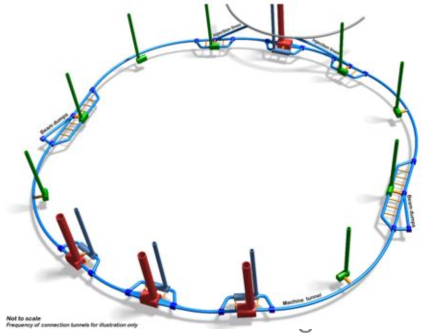
- FCC-hh target power: **500 MW**
- Power factor: 0.9
- Power requirement per point: based on LHC experience and inputs from FCC systems designers
- Machine operating cycle: similar to LHC
- Average power : steady state consumption
- Peak power : maximum @ end of ramp-up

- FCC-ee target power: **400 MW**
- Power factor: 0.9
- Power requirement per point: based on inputs from machine designers
- Machine operating cycle: Unknown
- Average power : average consumption during a physics run
- Peak power : not considered



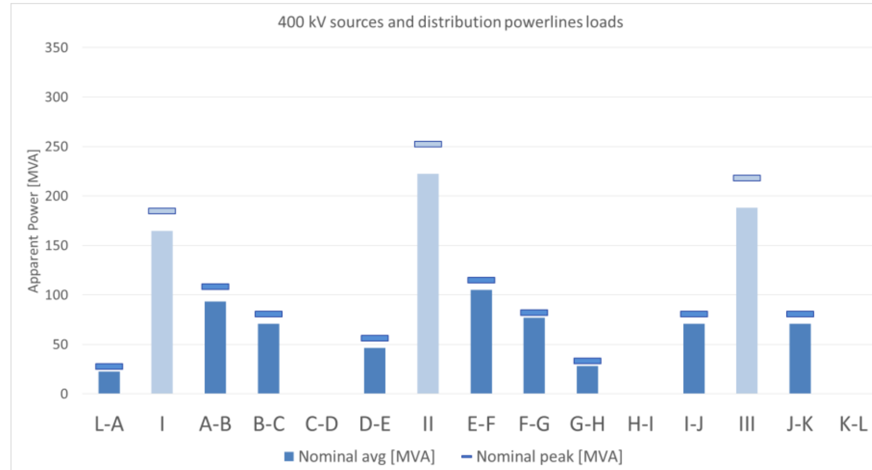


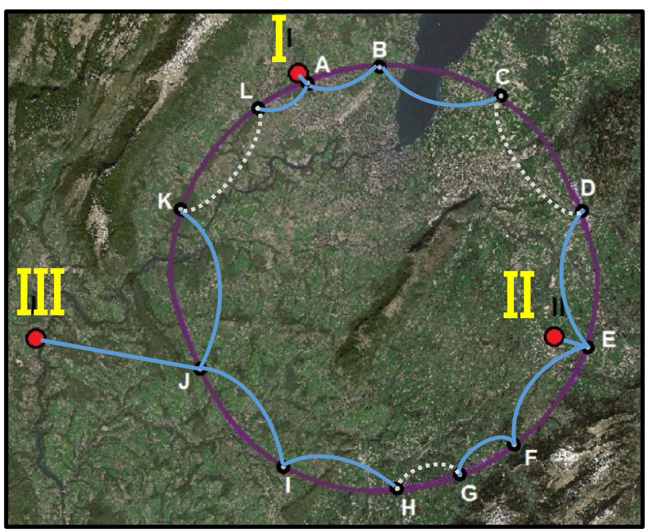
Design considerations

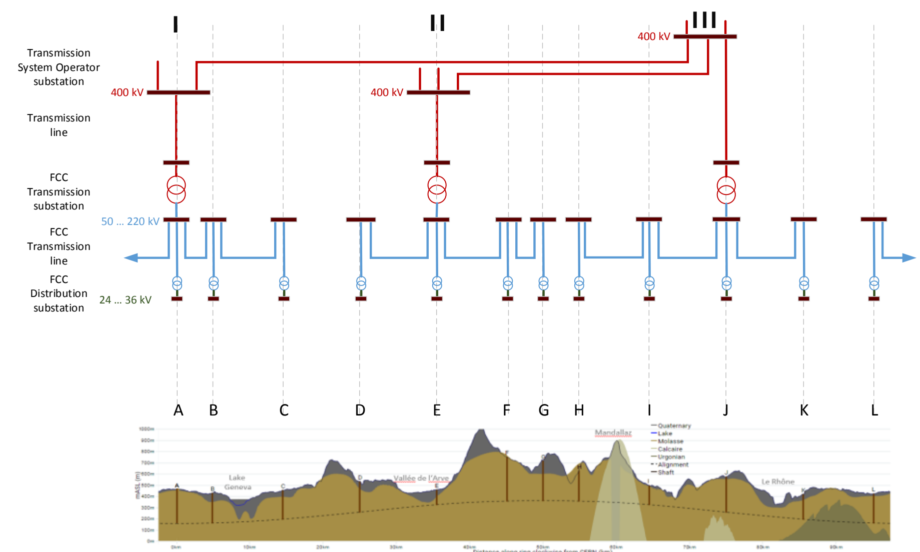


FCC-hh transmission power flow layout

- Case 1 : Nominal network
  - Three 400 kV sources available
  - Transmission lines between neighbouring points
  - Each source feeding four points

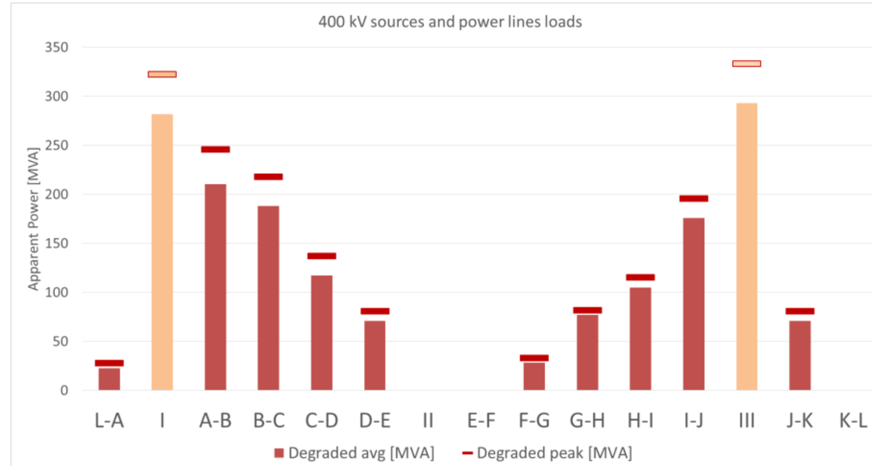


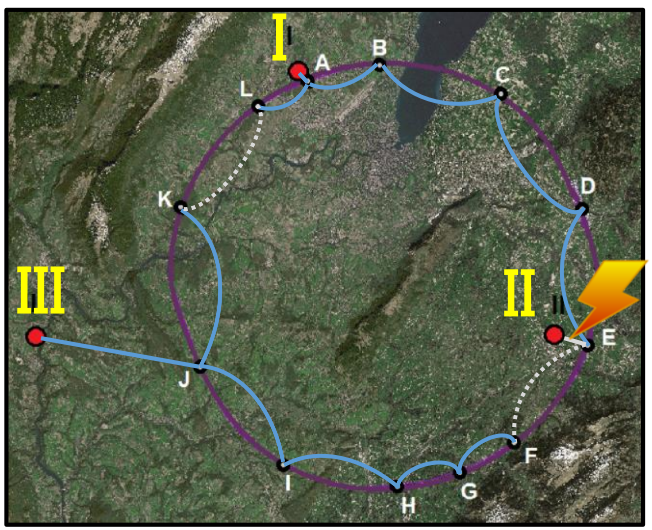


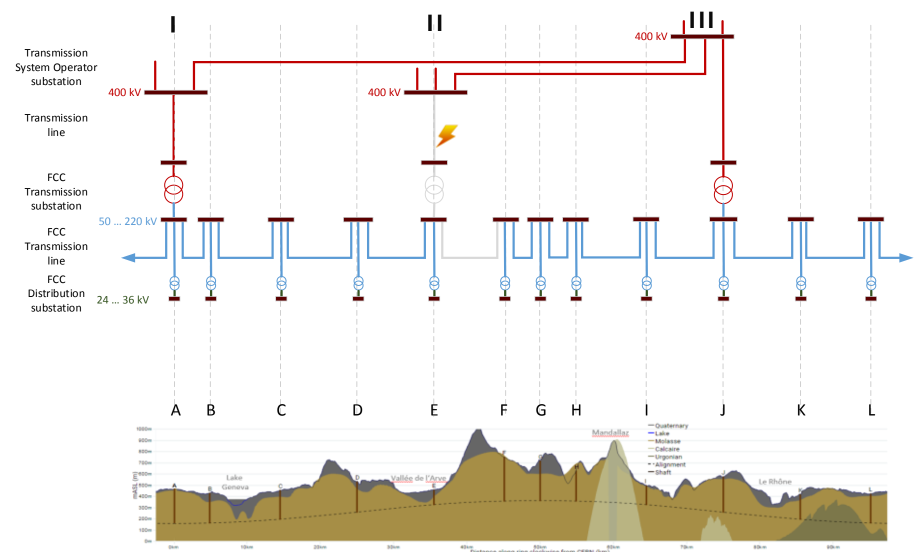


FCC-hh transmission power flow layout

- Case 2 : Degraded network
  - Source II not available
  - FCC-hh at nominal operation
  - Available sources feeding each six neighbouring points

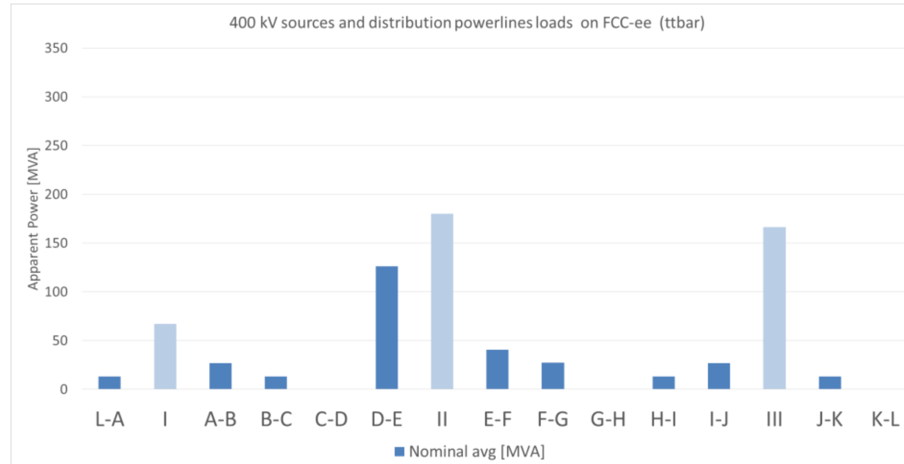


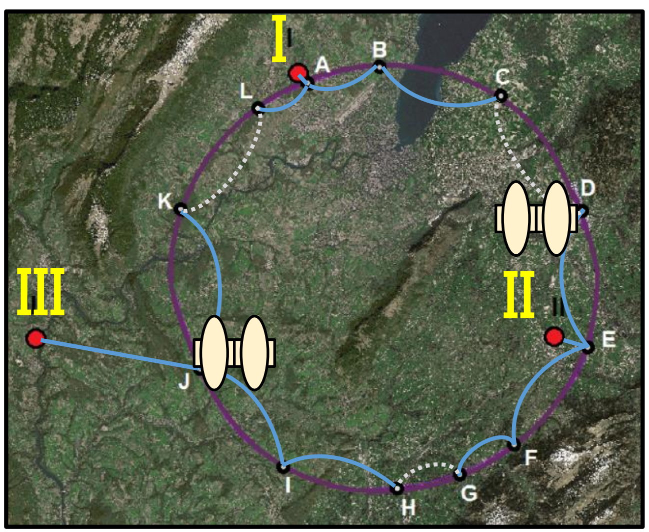


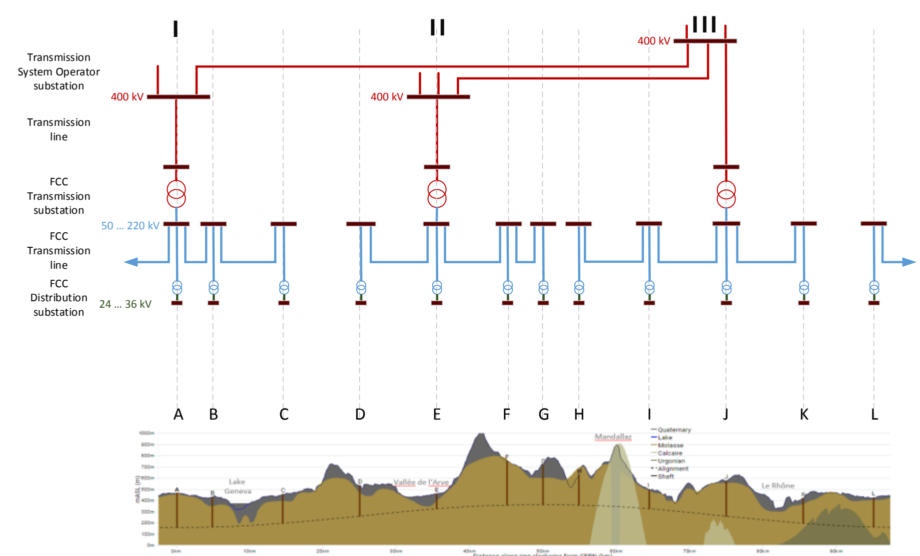


FCC-ee transmission power flow layout

- Case 1 : Nominal network
  - Three 400 kV sources available
  - Transmission lines between neighbouring points
  - Each source feeding four points

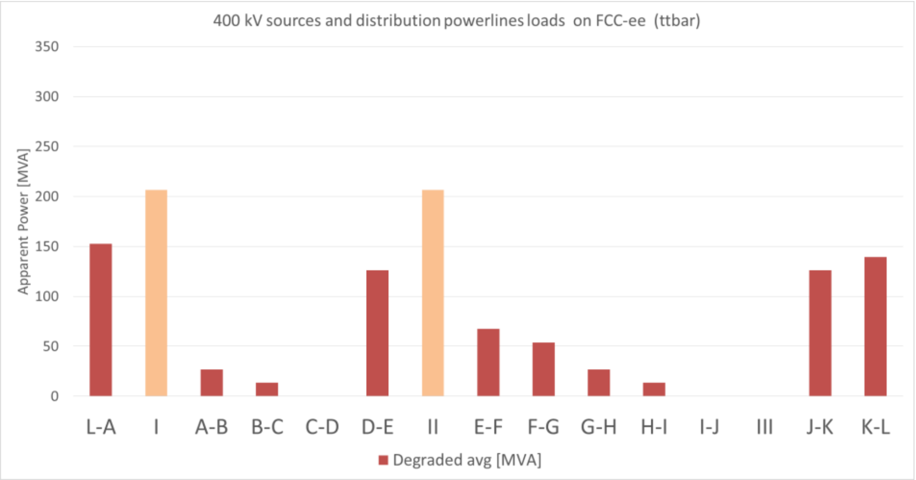


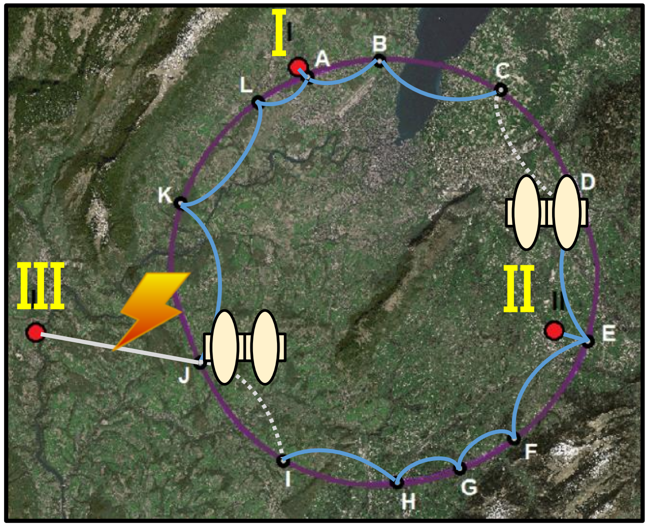


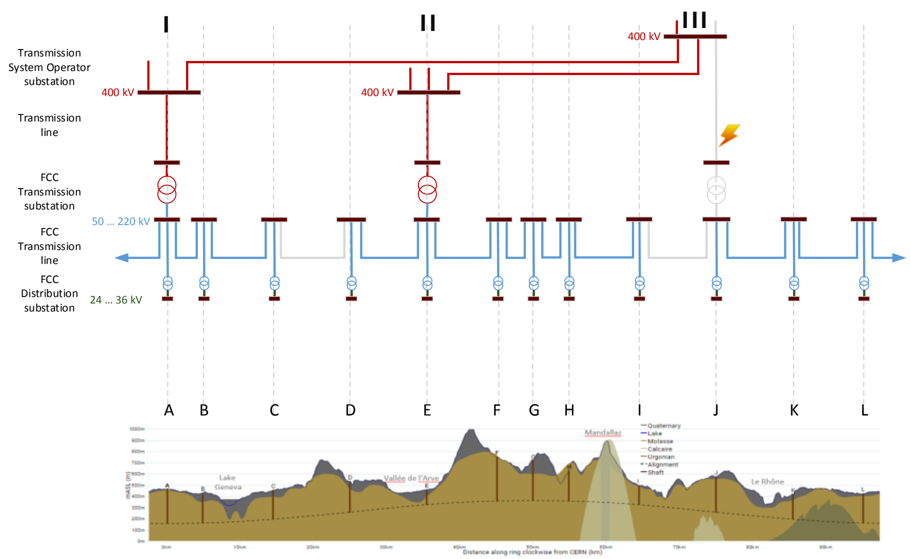


FCC-ee transmission power flow layout

- Case 1 : Degraded network
  - Source III not available
  - FCC-ee at nominal operation
  - Available sources feeding each six neighbouring points







Transmission lines installation - Surface vs. underground

- Transmission and distribution of the power from sources to FCC surface points and between points can be envisaged using two technologies

- **Overhead lines**
  - Majority of transmission lines as from 132 kV and higher
  - 15 years average delays to realise projects

- **Underground lines**
  - Used in urban areas and protected areas
    - Direct burial
    - Concrete ducts
    - Galleries

Power	150 MVA
Operating voltage	132 kV
Phase current	525 A
Line length	300 m

Type of installation	Parameters			Phase cross section [mm2]
Concrete embedded ducts	Thermal resistivity	K.m/W	2	**800**
	ground temperature	°C	35	
	Laying depth	mm	800	
Direct burial in ground	Thermal resistivity	K.m/W	2	**630**
	ground temperature	°C	35	
	Laying depth	mm	2000	
Burial in ground in HDPE ducts	Thermal resistivity	K.m/W	1	**400**
	ground temperature	°C	20	
	Laying depth	mm	800	
In gallery	Air temperature	°C	40	**300**
Overhead	Air temperature	°C	25	**170**

- FCC conceptual design studies consider overhead lines from source to nearest point and underground lines for transmission between points

Transmission lines dimensions and installation in the tunnel

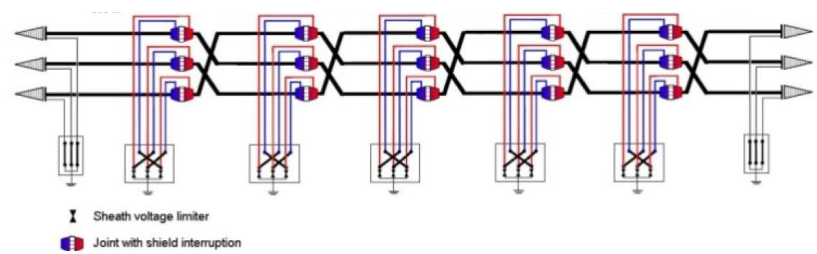
Dimensioning example

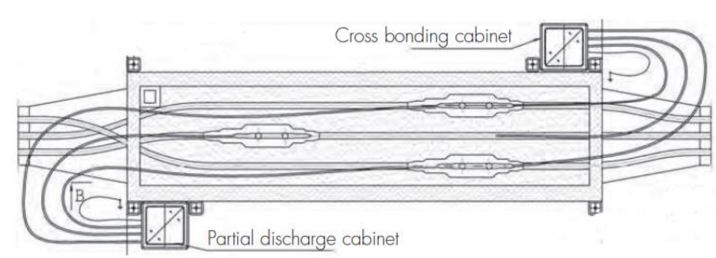
- Transmission line between two points
- based on FCC-hh target power requirements at normal and degraded network operating modes
- IEC standard voltage level of 132 kV for these study case
- Baseline voltage level proposal to be further studied

Case	Apparent power [MVA]	Operating Voltage [kV]	Conductor cross section [mm2]	Conductor material	Cable diameter [mm]	Max. transportable length* [m]	Installation method
Nominal Operation	120	132	800	Copper	95	1500	Trefoil
Degraded Operation	250	132	2000	Copper	126	960	Trefoil

Installation

- Cross bonding scheme is required to limit sheath induced longitudinal voltages and sheaths circulating currents
- Maximum transportable length will determine number of pits for cable joints and for cross bonding
- At 132 kV the pit dimension is of the order of 10 x 1.5 x 1 [m]



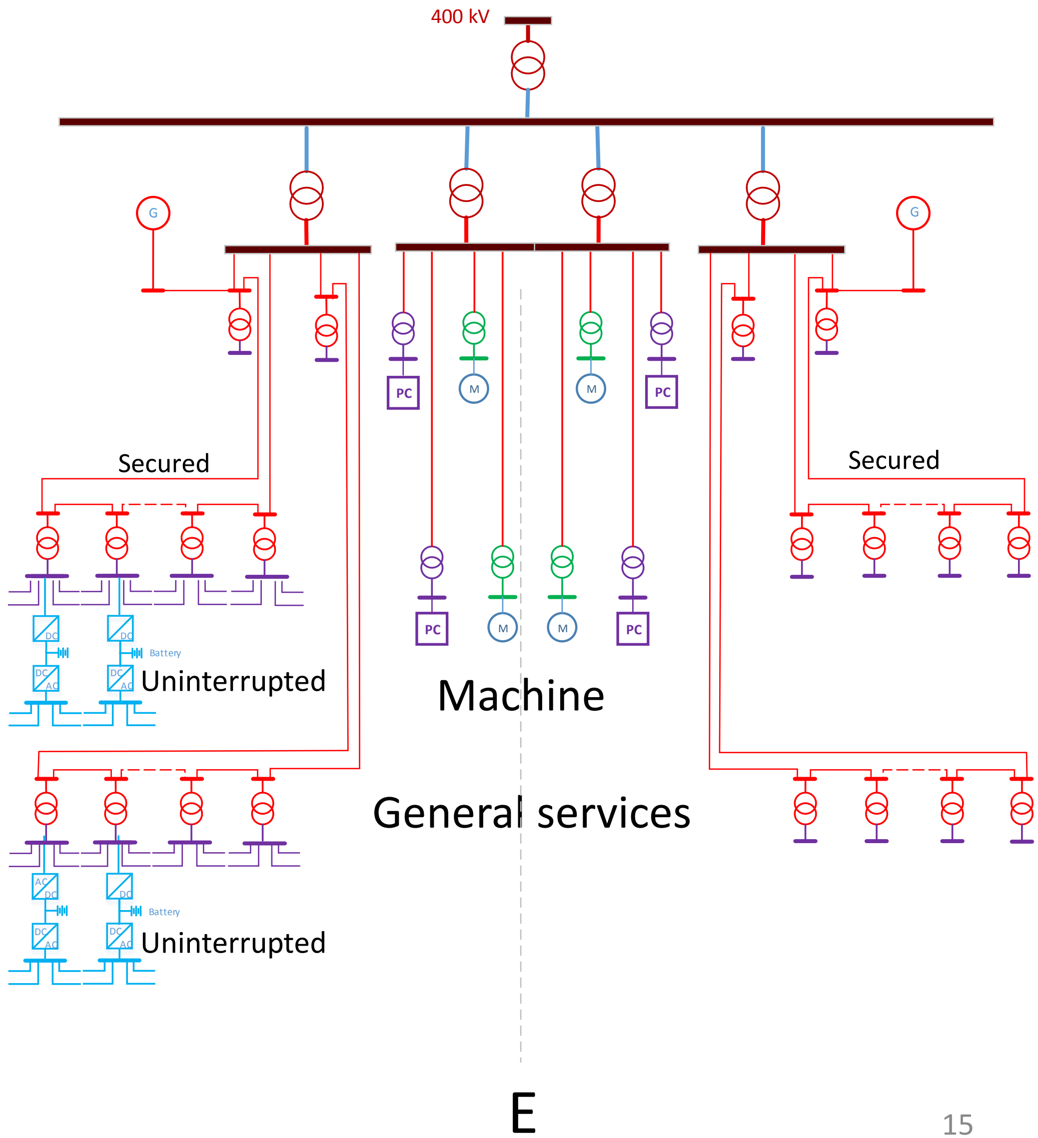


Distribution network – Example of one possible variant

- Dimensioning and topology strongly depends on systems process and power loads requirements

- Except for some equipment (cryogenic compressors, cooling and ventilation motors and power converters) the end users are supplied at 400 V level

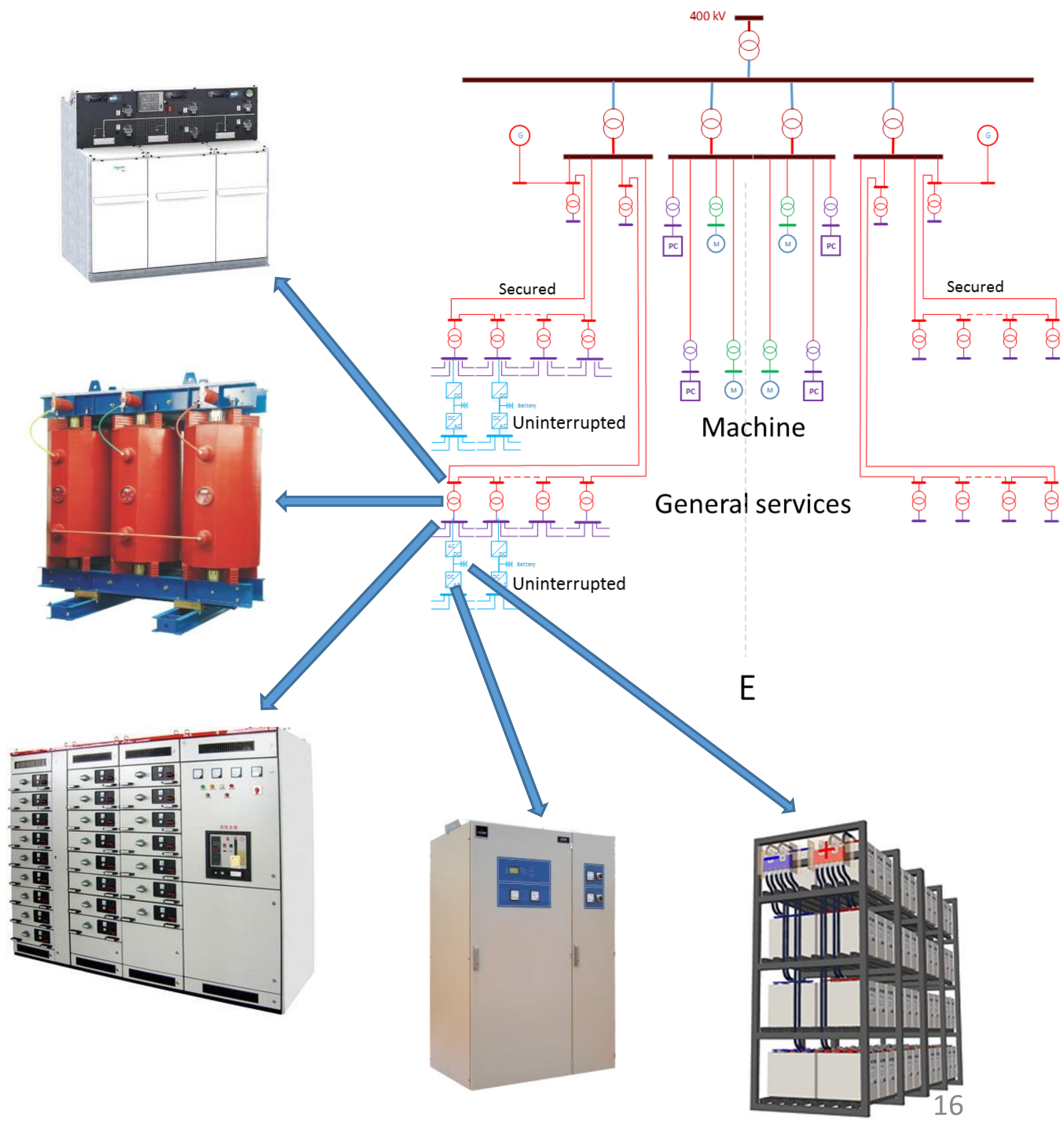
- 400 V and lower distribution network levels are limited in length to ≈ 800 m
  - Depending on maximum acceptable voltage drop (10 %) and maximum acceptable impedance allowing the detection of end line short circuits



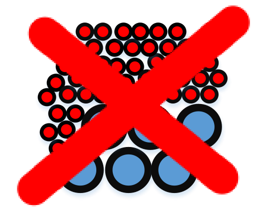
Underground installation of power distribution equipment

- Equipment concerned
  - Transformers
  - High voltage switchgears
  - Low voltage switchboards
  - UPS
  - Batteries
  - Control racks

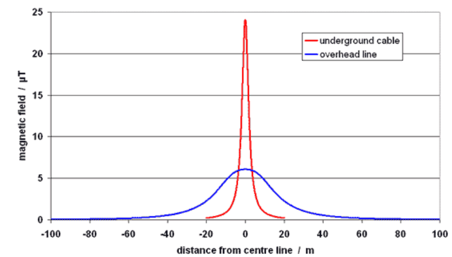
- Technical rooms are necessary along the arcs
- Clearance for transport and maintenance shall be considered in the tunnel and shaft cross sections



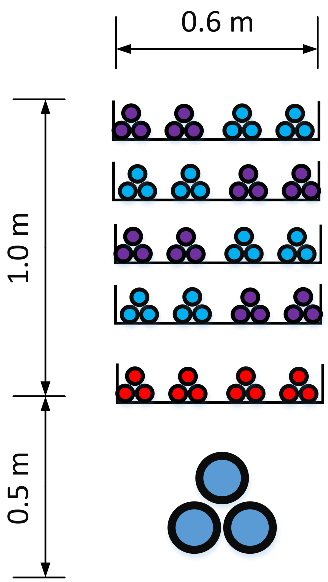
Requirements for tunnel and shaft cross sections



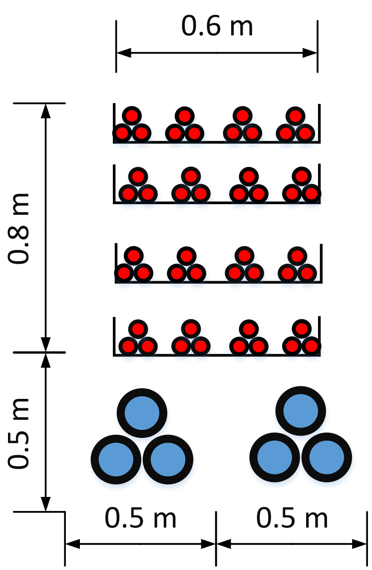
- Power carrying capacity is strongly dependant from vicinity between power lines
- Power lines magnetic field levels shall be considered due to possible influence on beams and occupational safety issues

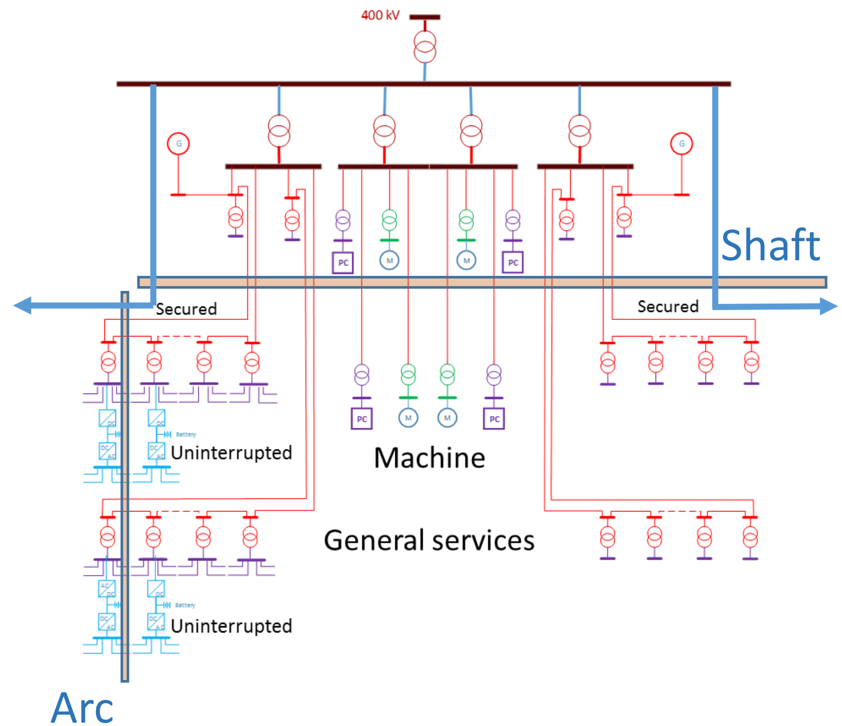


Arc power lines cross section



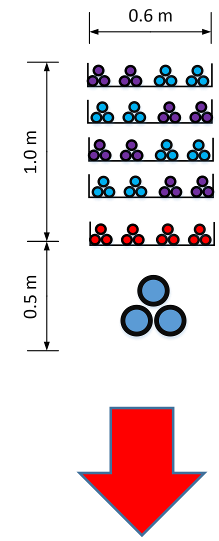
Shaft power lines cross section

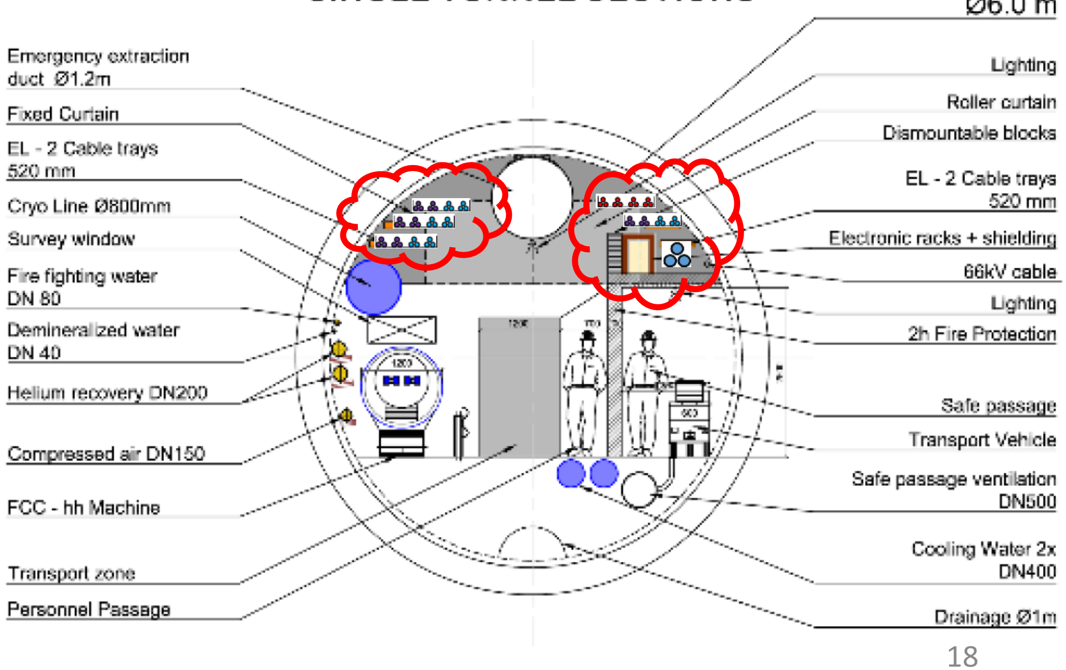




Arc single tunnel cross section

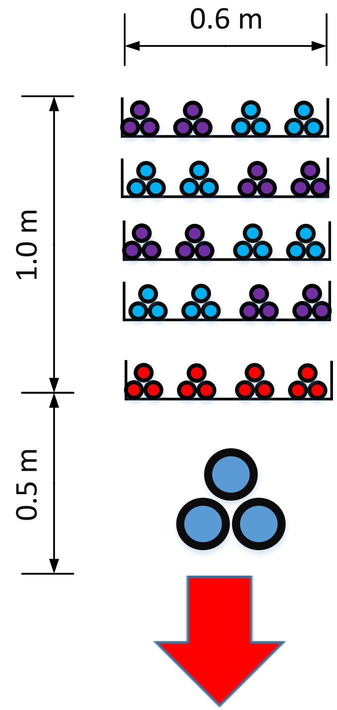
- Positioning of transmission and distribution line to be optimized
- For this study proposal five cable trays should be made available
- Transmission line require access to pits for joints and cross bonding
- Additional cable trays shall be made available for
  - routing of cables from distribution switchboards to end users
  - Routing of control cables and fibre optic network
  - Routing of local DC cables

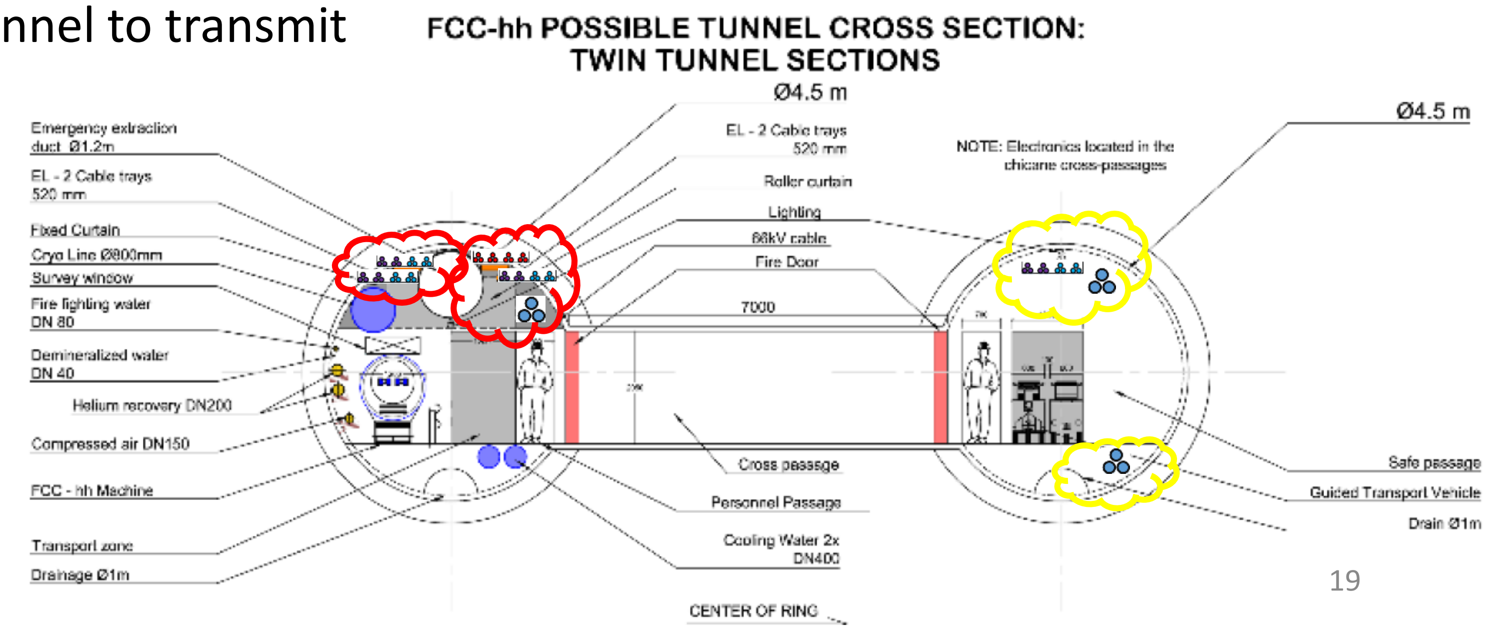




Arc twin tunnel cross section

- Same remarks as for single tunnel version applies
- Electrical loads in the second tunnel to be identified
- Distribution network to be designed to supply equipment located in the second tunnel such as lighting
- Address the possibility to use the second tunnel to transmit power





Considerations for underground civil engineering

- Need of technical rooms along the tunnels to host distribution electrical equipment
  - Frequency: typically 500 – 1000 m
  - Volume to be optimized according to other users requirements (if any)
- The tunnel transmission network will require pits for joints and cross bonding connections
  - Frequency: typically 800-1000 m
  - Typical dimension: 10 x 1.5 x 1 m
- Verify space allocation in tunnels and shafts cross sections variants for distribution and transmission lines
- Verify sufficient cross section and volume for the transport, handling and maintenance of electrical equipment in underground areas

Take away messages

Concluding remarks

- Dimensioning of the transmission network strongly depends from the desired accelerator(s) availability and reliability levels and from individual systems operating cycles and associated power requirements
  - Inputs from end users and systems designers are required
- Baseline topology for the distribution networks layouts require more precise data on power consumption from end users
  - Dedicated talks given by M. Mylona this afternoon
- No showstoppers on the feasibility of powering the FCC-hh and FCC-ee using standard off-the-shelf electrical equipment
- FCC-hh peak power require more studies (quantify it -> include it in the network dimensioning?, evaluate local storage?,…)

Future steps

- Gather end users and systems power requirements and topologies
- Verify the cohabitation in tunnel of high voltage transmission lines with beam and occupational safety requirements
- Validate the baseline layouts for the conceptual design of the transmission and distribution networks
- Identify, study and implement in the conceptual design study the peak consumption management, network stability and compensation requirements
- Study space requirements for end users cabling, control cables, fibre optics networks and DC air and water cooled cables

Thank you for your attention

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