Design considerations for the FCC electrical network architecture

FCC week 2016, Rome, 10-15 April 2016

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

Setting the scene
- Powering a 100 km underground accelerator
- Typology of networks for accelerators
- FCC-hh and FCC-ee power requirements

Design considerations
- Transmission network
- Distribution network
- Installation aspects
- Civil engineering requirements

Take away messages
- Concluding remarks
- Next steps
Setting the scene

Not to scale
Frequency of connection tunnels for illustration only
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

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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

- 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

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

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 dependent on 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