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

<table>
<thead>
<tr>
<th>System</th>
<th>FCC week 2015</th>
<th>FCC week 2016</th>
<th>FCC week 2017 Machine designers</th>
<th>Scaling from LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCC-hh</td>
<td>585</td>
<td>555</td>
<td>423</td>
<td>347</td>
</tr>
<tr>
<td>Injectors</td>
<td></td>
<td></td>
<td>122</td>
<td></td>
</tr>
<tr>
<td>Data centers</td>
<td></td>
<td></td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

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.

Values expressed in MW – Considered Power Factor = 0.9
Power Requirements at each FCC-hh Point

- Power distribution location according to systems layouts

<table>
<thead>
<tr>
<th>FCC week 2017</th>
<th>Machine designers</th>
<th>Scaling from LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>423</td>
<td>347</td>
<td></td>
</tr>
</tbody>
</table>

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)
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

Nominal scenario

Degraded scenario A: source I unavailable
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

60 MVA

25 MVA

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

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

3 x 2 x 220 MVA
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

<table>
<thead>
<tr>
<th>Point</th>
<th>Power rating (MVA)</th>
<th>Transformers x point</th>
<th>Installed power [MVA]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>220</td>
<td>60</td>
<td>25</td>
</tr>
<tr>
<td>A</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>E</td>
<td>2</td>
<td>2</td>
<td>0</td>
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<tr>
<td>F</td>
<td>0</td>
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<td>G</td>
<td>0</td>
<td>2</td>
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<tr>
<td>H</td>
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</tr>
<tr>
<td>I</td>
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<td>2</td>
<td>0</td>
</tr>
<tr>
<td>J</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>K</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>L</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Tot. quantity</td>
<td>6</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>Tot. installed Power [MVA]</td>
<td>1320</td>
<td>840</td>
<td>250</td>
</tr>
<tr>
<td>Type of network</td>
<td>End users voltage level</td>
<td>Loads type</td>
<td>Users individual power range</td>
</tr>
<tr>
<td>-----------------</td>
<td>------------------------</td>
<td>------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Machine</td>
<td>24 kV 3.3 kV 400 V</td>
<td>Power converters, cooling and ventilation motors, radio frequency</td>
<td>200 W To 1000 kW</td>
</tr>
<tr>
<td>General Services</td>
<td>400 V</td>
<td>Lighting, pumps, vacuum, wall plugs</td>
<td>50 W To 200 kW</td>
</tr>
<tr>
<td>Secured</td>
<td>400 V</td>
<td>Personnel safety: Lighting, pumps, wall plugs, elevators</td>
<td>5 W To 100 kW</td>
</tr>
<tr>
<td>Uninterruptable</td>
<td>400 V</td>
<td>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</td>
<td>5 W To 100 kW</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Users</th>
<th>Network type</th>
<th>Schematic layout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generic power sockets</td>
<td>General Services</td>
<td></td>
</tr>
<tr>
<td>Users power sockets</td>
<td>Secured</td>
<td></td>
</tr>
<tr>
<td>Controlled lightning</td>
<td>General Services</td>
<td></td>
</tr>
<tr>
<td>Permanent lightning</td>
<td>Secured</td>
<td></td>
</tr>
<tr>
<td>Evacuation lightning</td>
<td>Uninterruptable</td>
<td></td>
</tr>
<tr>
<td>Antipanic lightning</td>
<td>Uninterruptable</td>
<td></td>
</tr>
<tr>
<td>Safety systems</td>
<td>Uninterruptable Double redundancy</td>
<td></td>
</tr>
<tr>
<td>Communication / Star points</td>
<td>Uninterruptable</td>
<td></td>
</tr>
<tr>
<td>Machine Protection</td>
<td>Uninterruptable Double redundancy</td>
<td></td>
</tr>
<tr>
<td>Beam protection</td>
<td>Uninterruptable Double redundancy</td>
<td></td>
</tr>
<tr>
<td>Quench protection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cryogenics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vacuum</td>
<td></td>
<td></td>
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<tr>
<td>Beam Position</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam Loss</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vacuum</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Load</th>
<th>FCC-hh Arc power consumption estimate* [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 km</td>
</tr>
<tr>
<td>General services</td>
<td>26.17</td>
</tr>
<tr>
<td>Uninterrupted</td>
<td>8.25</td>
</tr>
<tr>
<td>Secured</td>
<td>1.80</td>
</tr>
<tr>
<td>Power transformers</td>
<td>2.08</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>36.22</strong></td>
</tr>
</tbody>
</table>

* 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

It works but not an optimized scheme
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.
The emergency stop system is a safety system installed where danger to personnel may occur. Activation of the emergency stop system cuts all electrical installations in the building(s) or area(s) concerned. Exceptions where a supply is needed for other safety related systems. In case of an emergency stop activation, an alarm is generated to trigger intervention.
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/km²/year

* Image of SMES: Courtesy of Brookeaven Lab, as Presented at the Tenth EPRI Superconductivity Conference, 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 and 20 kV
• Access points are located in urbanised and agricultural areas
Space Requirements
Outdoor / Indoor Substations

- Diesel power station: 2 x 1.25 MW
- Surface indoor substation
- Outdoor park for 24 kV
- Network Compensation and Filtering

Surface Outdoor Substation
- 400 / 132 / 24 kV
- Feeders to Substations

Transmission line to adjacent point

Incoming 400 kV Line from European Grid
- 400 / 132 / 24 kV
- Control and protection Room

AC/DC

- Local Source of Supply
  - Diesel Power Station
  - Typically 1 – 3 MVA

- Underground distribution

145 kV
- Dry type transformers

- 400 kV Gas insulated
- 400 kV Air insulated

- B-C-D-F-G-H-I-K-L
- A, E, J

- Actually in the early industrialization phase
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