FCC Power Transmission Network Studies

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Introduction

Feeding a 100 km accelerator such as Future Circular Collider (FCC) requires a robust and highly available power transmission network. The aim of this study is to prove the feasibility of feeding FCC from the European grid, proposing a baseline concept for the transmission system which takes into account nominal and degraded operating scenarios. Estimation of power requirements, mapping of available power sources and identification of possible power system layouts are presented.

FCC-hh power requirements

The power requirements of FCC hadron-hadron collider (FCC-hh) are estimated based on a) the scaling from LHC consumption per each user (cryogenics, cooling, ventilation, RF etc.) and b) the estimations from machine design experts (Table 1). The injectors and data center power needs are also taken into account in order to have an overview of the overall required power. The range of the power needs at each of the 12 points of the accelerator are given in Figure 1 and are based on the FCC-hh baseline layout represented in Figure 2.

System	a) Scaling from LHC [MVA]	b) Machine designers [MVA]
FCC-hh	347	423
Injectors	122	
Data centers	7	

Table 1: FCC-hh power requirements based on LHC extrapolation and machine design experts

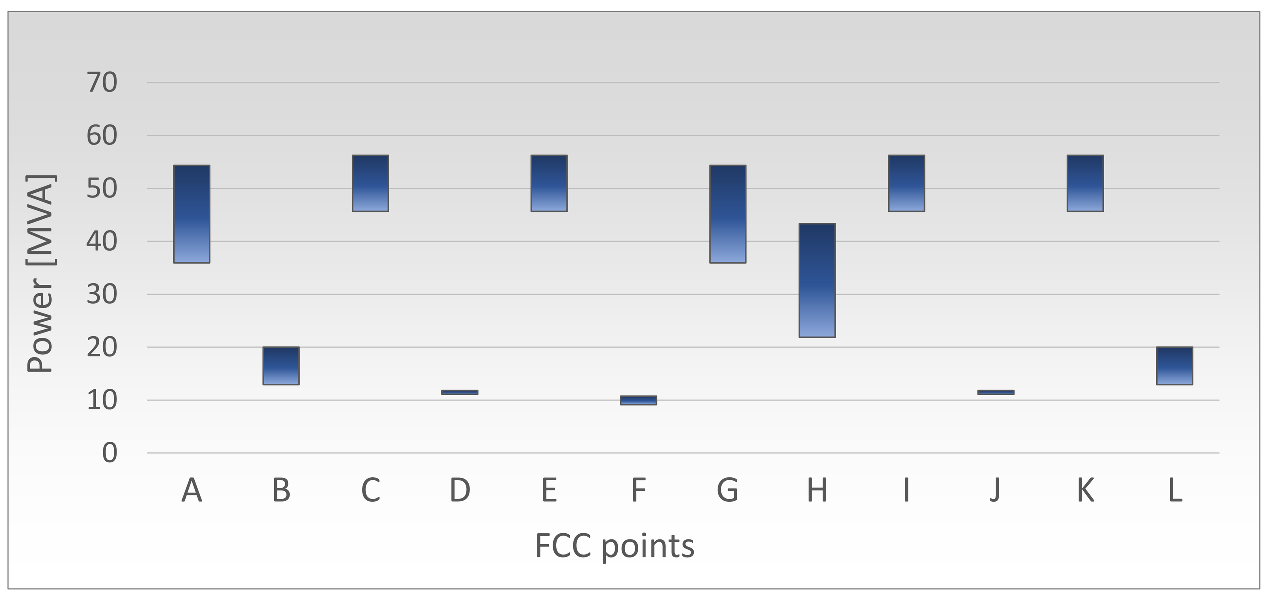

Figure 1: Range of FCC-hh power requirements

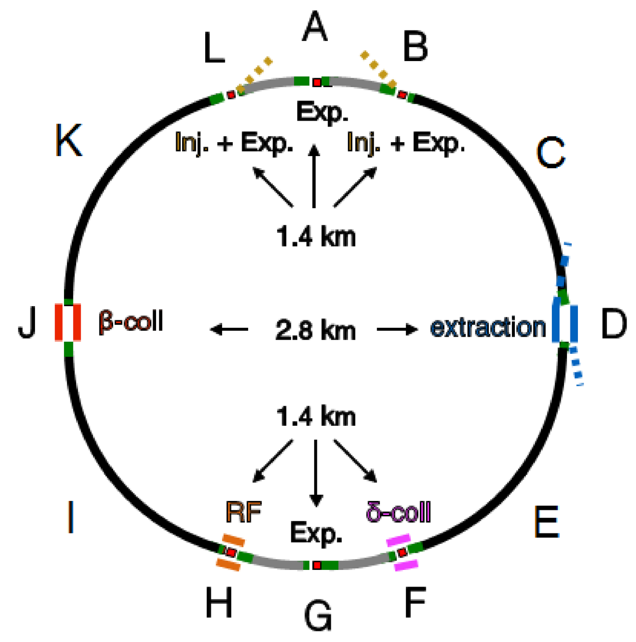

Figure 2: FCC-hh baseline layout

Powering system layout

Based on the European grid layout, three 400 kV primary sources (Fig.3: sources I, II, III), with available power of 200 MVA each, have been identified as the most robust sources to feed in nominal operation the FCC accelerator and its injectors. For the baseline layout, the nominal and two degraded operating scenarios are studied in order to verify the feasibility of feeding the accelerator:

- **Nominal operation:** Accelerator fully operating with beam and supplied from the normally available sources.
- **Degraded scenario A:** Accelerator fully operating and one of the three sources not available.
- **Degraded scenario B:** Accelerator in stand-by mode. In this scenario users consume their base power.

In degraded scenarios the reconfiguration of the connecting lines between points will provide the necessary power and will equally load the two remaining sources.

Different layouts of the transmission network are studied. In the layout I the baseline is presented and in layouts II and III alternative solutions are proposed.

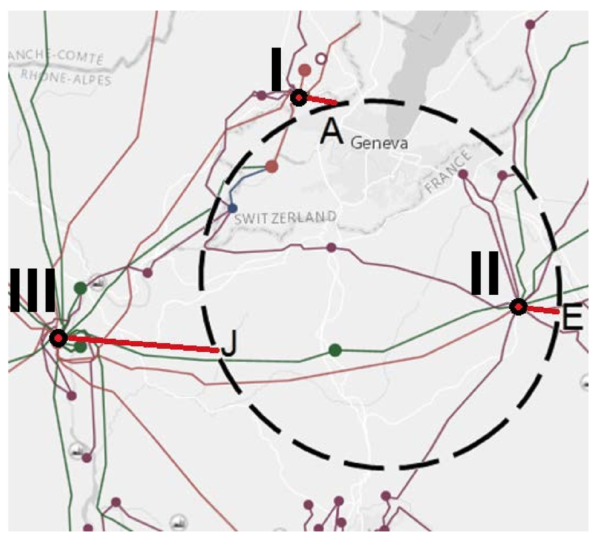

Figure 3: European grid with three 400 kV power sources and transmission lines (red) connecting to FCC

Layout I (Baseline): Incomer points fed from three 400 kV sources

Three sources are connected to three points (points A, E and J), from there the power is distributed to the remaining 9 points.

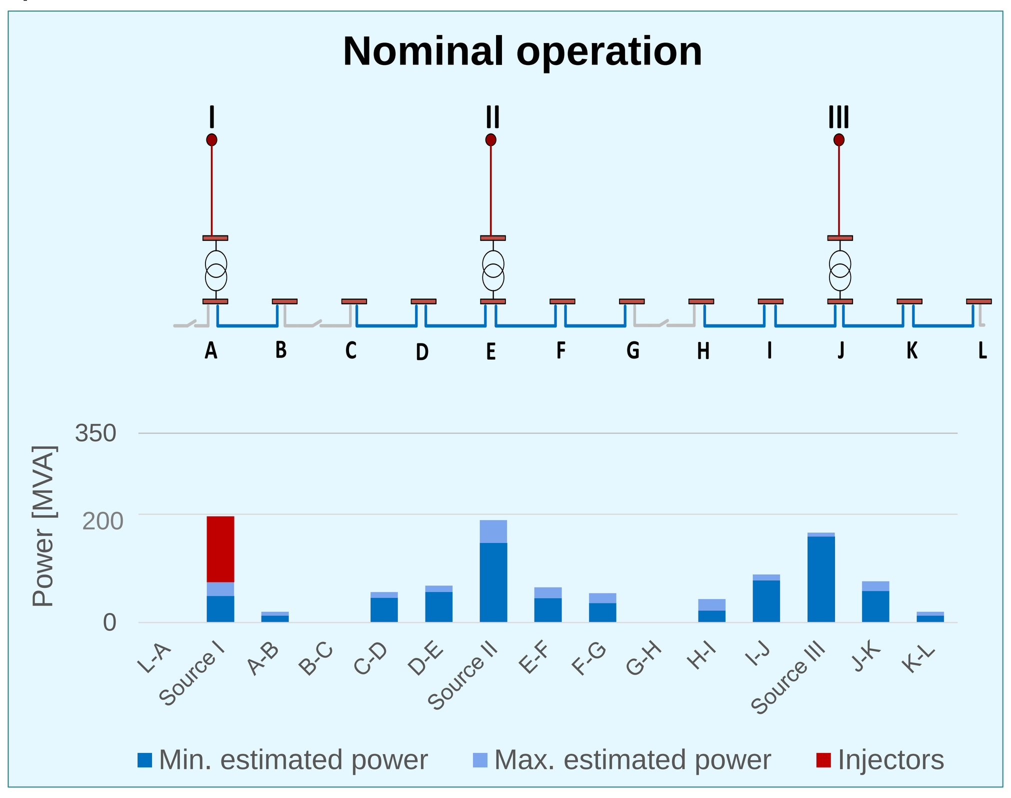

Figure 4: Transmission system layout (up) and load of sources and power line sectors (down) in nominal scenario

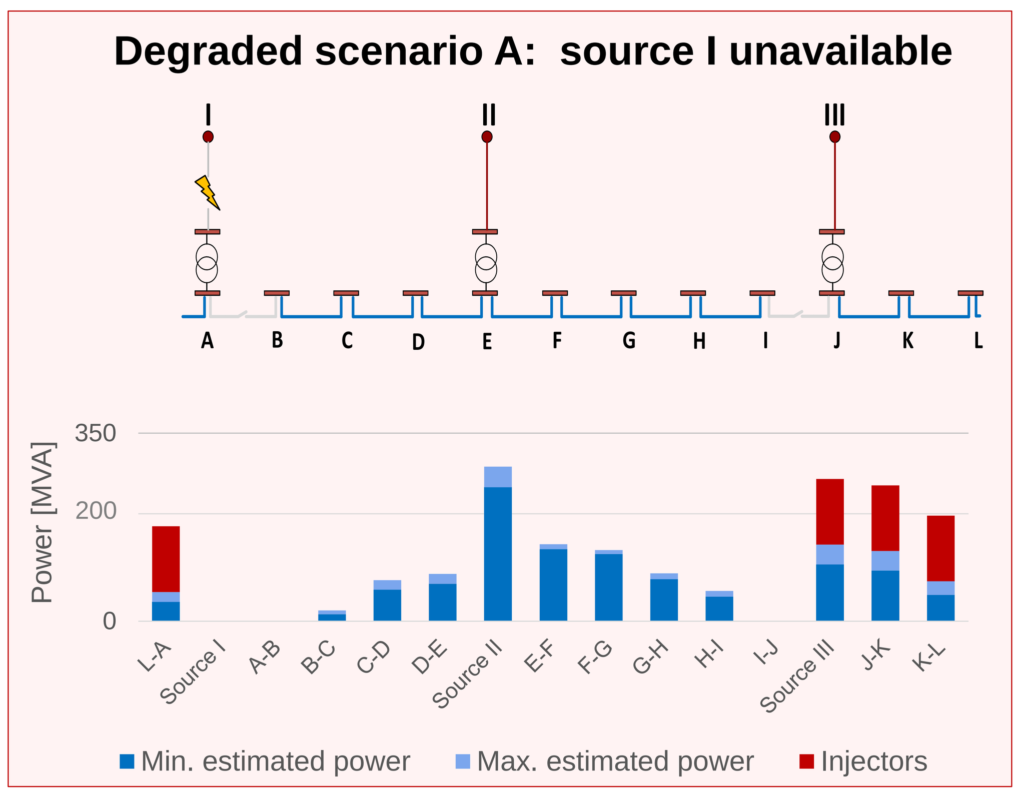

Figure 5: Transmission system layout (up) and load of sources and power line sectors (down) when source I is not available

For the dimensioning of the electrical transmission infrastructure, the maximum power load required at each source and maximum power flow in the sectors between points have been calculated. The maximum power loads have been calculated for unavailability of each one of the three sources. Figures 6 and 7 show the result of the overall maximum values within the nominal and three degraded scenarios.

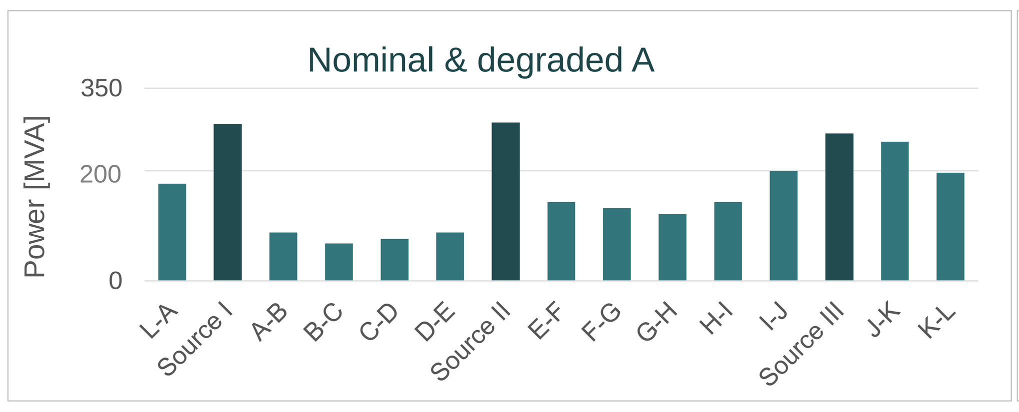

Figure 6: Maximum power load in nominal and degraded scenario A

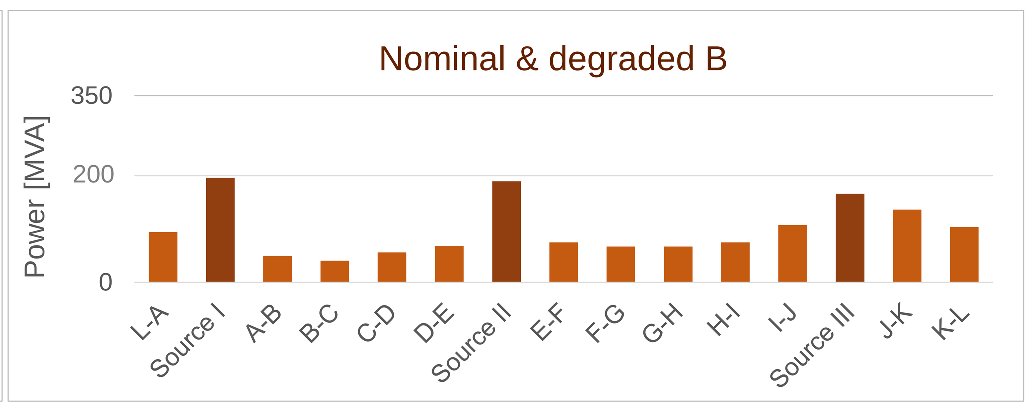

Figure 7: Maximum power load in nominal and degraded scenario B

Layout II: All points radially fed from three 400 kV sources

The three 400 kV sources feed each point through dedicated power lines and substations. Interconnection of the points are also available for redundancy. This option requires twelve power lines, compared to the baseline that has three power lines.

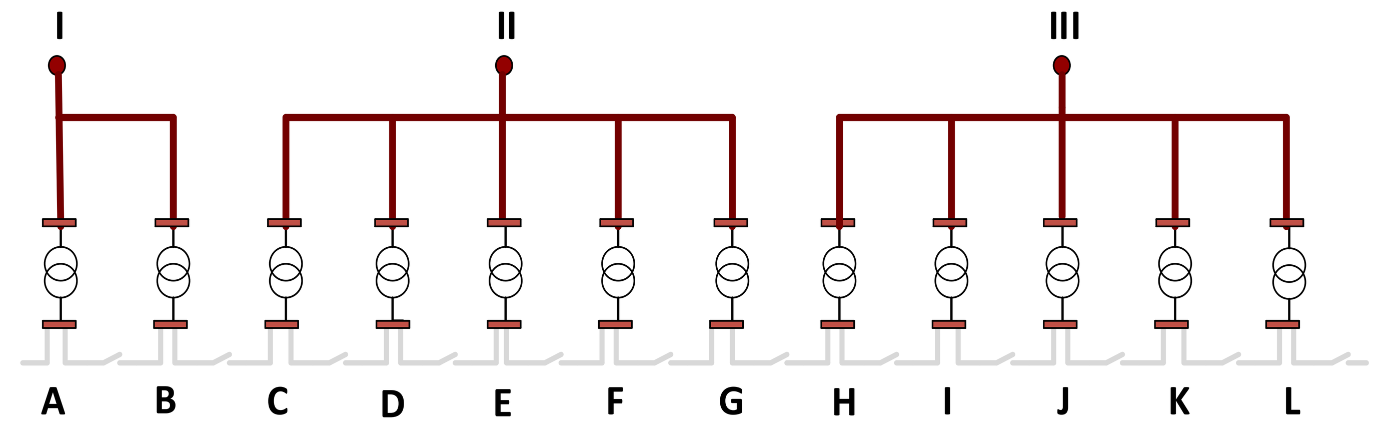

Figure 8: Transmission system layout in radially feeding option

Layout III: Mixed network, powered from primary and secondary sources

Power sources of lower voltage level (220 and 135 kV) are available and are fed from the three 400 kV sources. The use of primary and secondary sources can provide alternative and optimized powering scheme.

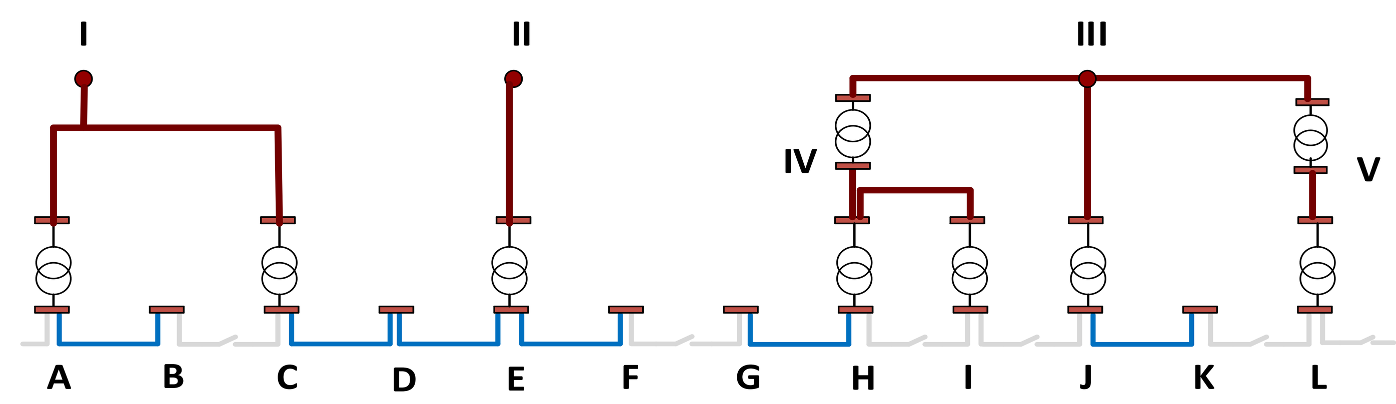

Figure 9: Transmission system layout in mixed network

Transmission line layout

Independently from the retained powering system layout, it is required to interconnect each point with its adjacent points by means of transmission lines. Four different line layouts are possible:

- **Aerial lines:** Transmission lines will cross mountains and residential areas. Feasibility is possible, probably combined with buried lines.
- **Buried lines on surface:** This option requires civil engineering work (trenching) on the surface. Feasibility is possible, probably combined with aerial lines.
- **Installation in the tunnel: (Baseline)** The option of installing the transmission lines into the FCC tunnel takes profit of the "existing" infrastructure. Cohabitation with the accelerator, safety and operational aspects require a detailed feasibility study.
- **Superconducting transmission lines in the tunnel:** Depending on power rate level, use of superconducting transmission lines can be an alternative option. This option would also benefit from the FCC tunnel infrastructure. Comparative study can focus on the feasibility of this solution.

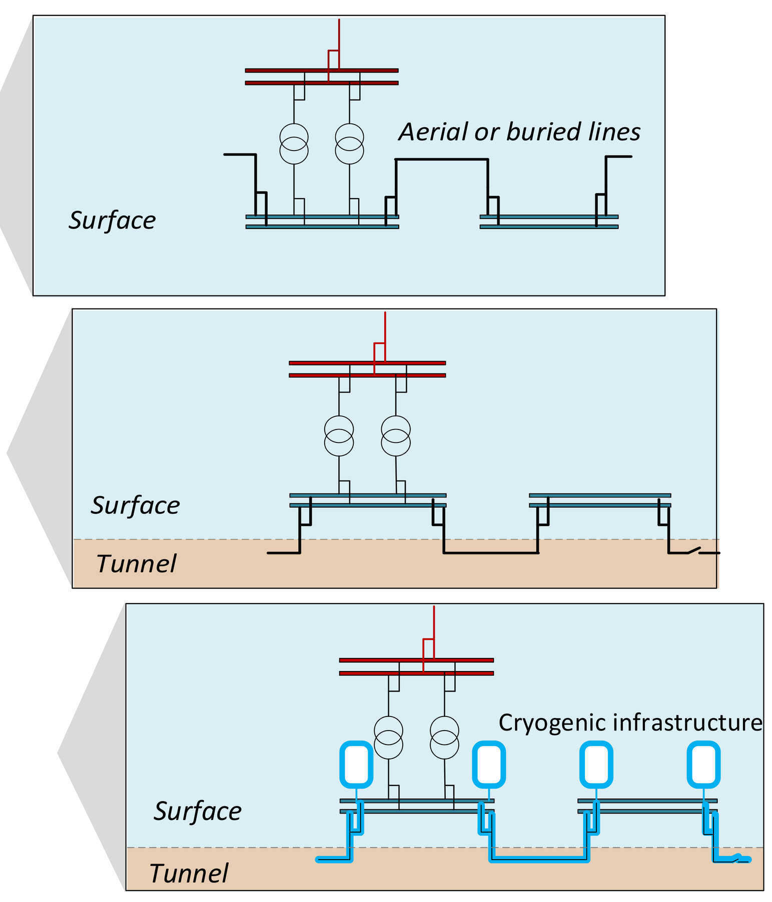

Figure 10: Possible transmission line layouts

Integration

According to the baseline layout, the transmission line through the tunnel will be composed of power cable segments and joints which will be located approximately every 1.5 kilometer. The transmission line is installed in the service shafts connecting one point to the adjacent one, passing through the tunnel. The cables and the joints are installed in cable trays or fixed in the wall with specific supporting systems.

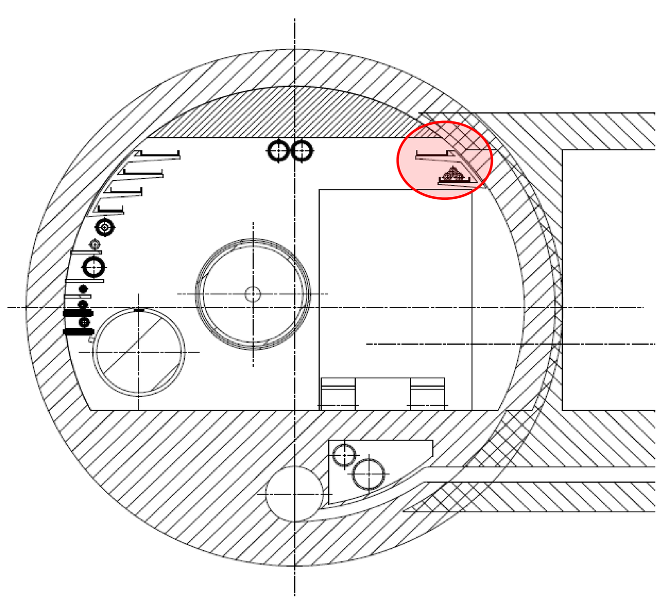

Figure 11: Integration of transmission line in the tunnel

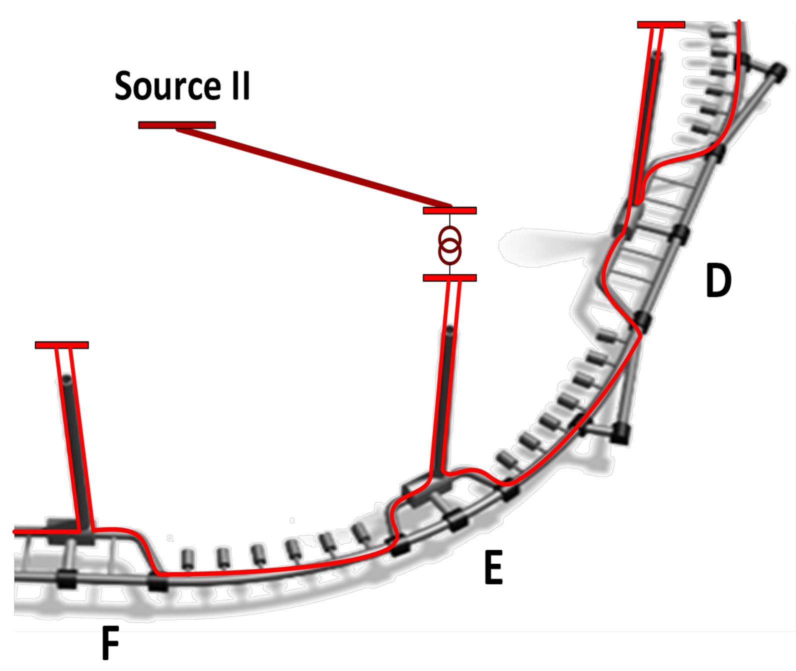

Figure 12: Example of transmission line path

Conclusion

A feasibility study of powering FCC-hh accelerator and its injectors from the European grid, showed that the rate of the available power sources fulfils the requirements of nominal operation. In case of unavailability of one of the three primary sources, the network is able to provide the base power to maintain the accelerator in stand-by mode. Possibility of keeping the accelerator fully operational in case of degraded operation, is feasible only with major changes in the European grid. Possible layouts of the transmission lines are available including installation on surface and underground. Integration of the transmission line into the FCC tunnel can benefit from the accelerator infrastructure. Implementation of superconducting lines has also been considered. A comparative study between resistive and superconducting lines will be performed in order to prove the efficiency of each option.

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