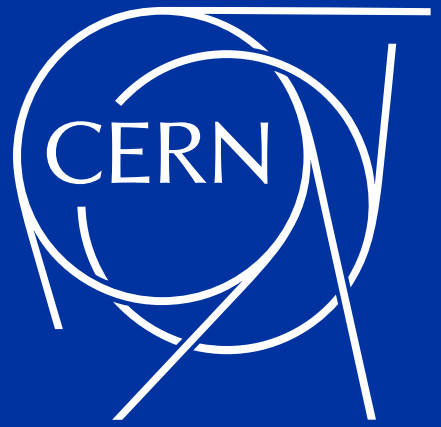

Status of RF Powering Studies

Manuel Colmenero, Davide Aguglia, Serge Pittet

04/10/2024

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  - Why a new powering solution is needed
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- **Feasibility Study and Pre-TDR Report**
  - What is our plan to deliver the expected results?
  - Which information do we need from SY groups to continue the studies?
- **Conclusions**

RF System Powering Challenges

Why is a new powering solution needed?

- ➢ Current solution (LHC) is based on individual powering of small group of klystrons

- Is it an issue to do the same for the FCC?→ **Yes: large converter footprint**

- ➢ Converter topologies used nowadays are high-network polluters (harmonics + reactive power)

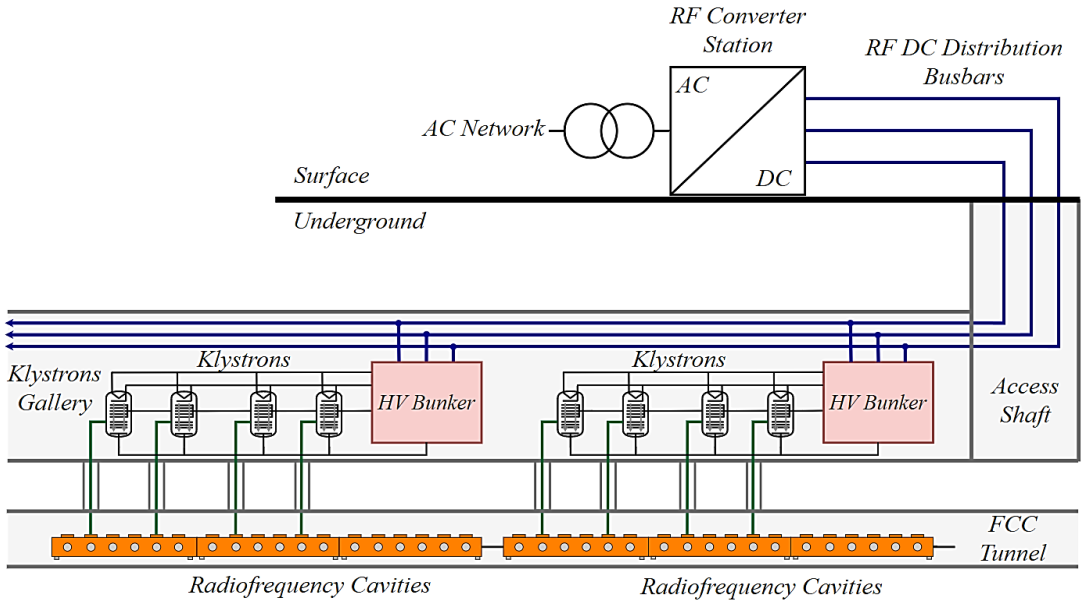
- How would we address this in the case of the FCC? **Installing an SVC park significantly impacting PH surface**

Need to investigate a **new powering strategy** based on a new converter topologies

Status of the studies: Powering Strategy

Powering proposed is based on centralizing the main power converter

- Single AC/DC power converter situated on the surface of Point H
  - Power > **150 MW**
  - DC voltage: **50-70 kV**
  - Good harmonic and reactive power performance
- **Single busbar scheme**: Klystrons are connected in parallel
  - More than a hundred RF amplifiers in parallel
  - Klystrons share the same DC voltage

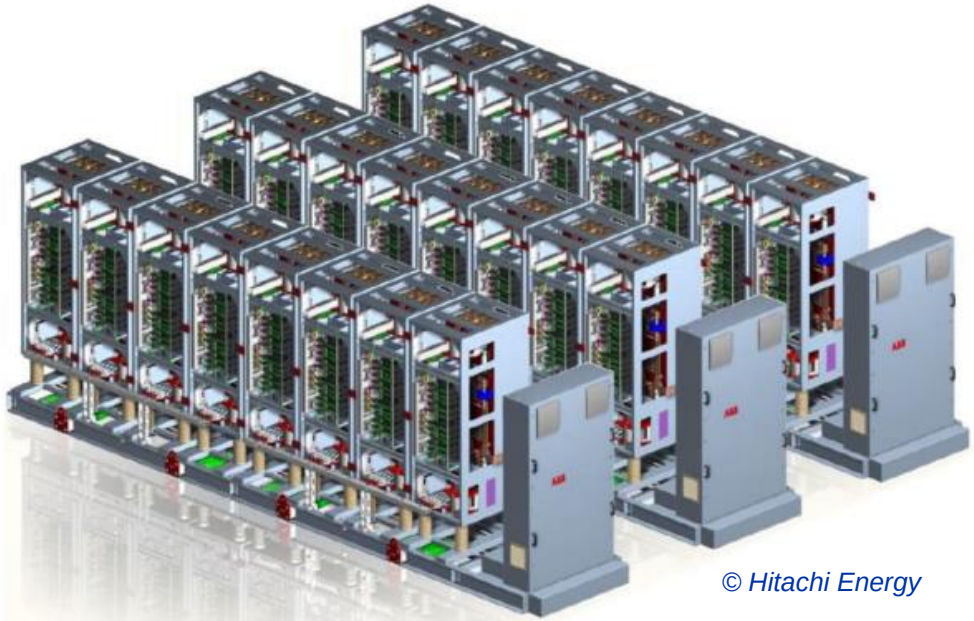


- **Challenge 1**: Guarantee **high reliability and efficiency** of the solution
- **Challenge 2**: **RF controllability** (individual klystron control) and **protection**
- **Challenge 3**: **Integration** of the power converter and HV equipment/switchgear

Status of the studies: Powering Strategy

Challenge 1: Ensure high reliability and efficiency of the powering solution

- New Converter Topology: **Modular Multilevel Converter**
  - Standard solution in industry: up to 640 kV
  - Modular: High reliability (demonstrated in HVDC)
  - High-Efficiency: > 98%
  - Excellent harmonic performance



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Where are we now?

- ✓ Simulation studies conducted for the topology
- ✓ CAPEX/OPEX Models
- ✓ Contacts with industry (Hitachi, Siemens…)
- ✓ Visit to HVDC station

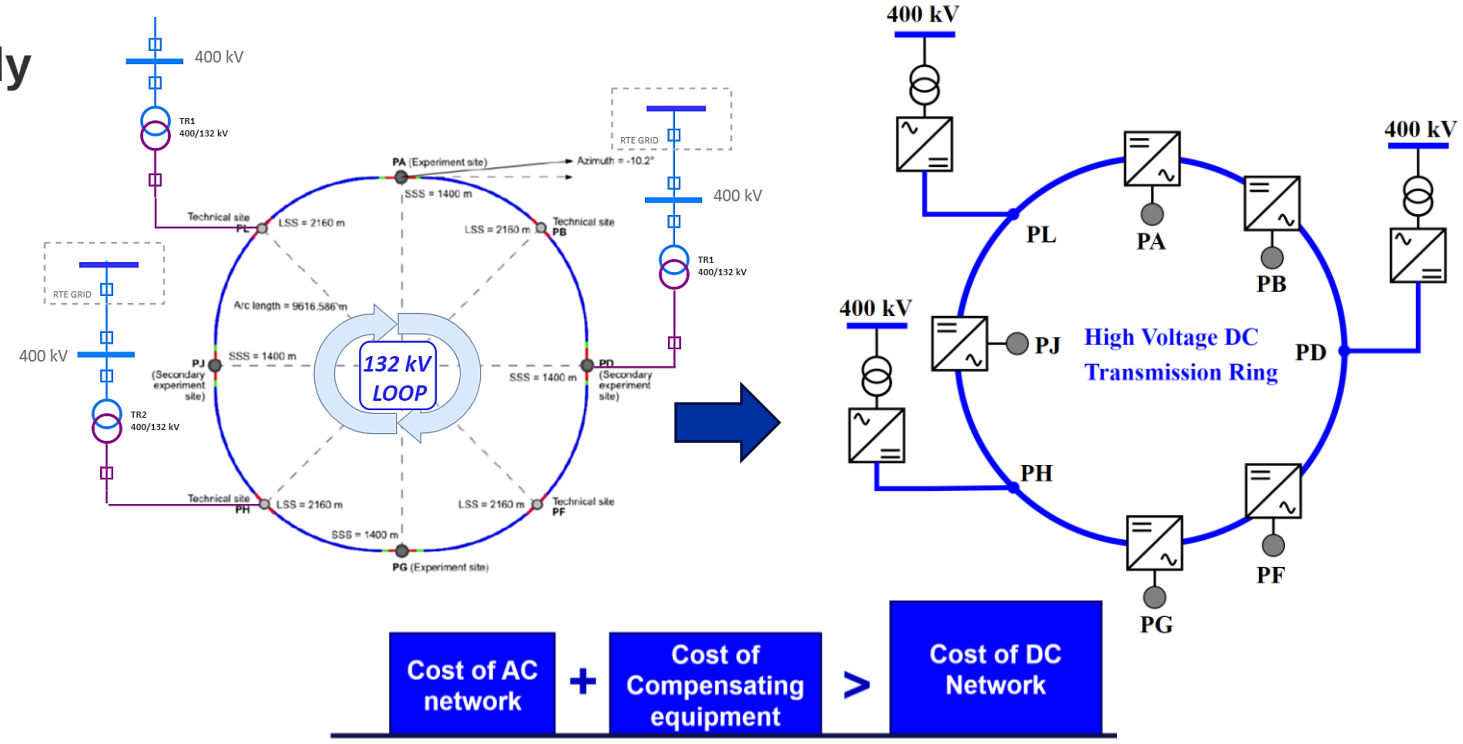
What is missing?

- Challenging technology → R&D
- Studies conducted by industry
- Placement of the RF station at PH
- Civil engineering requirements

Powering Strategy: DC VS AC

Studies are being conducted by EPC to study a DC powering solution for the FCC

- **Related to the RF powering Studies**
  - Similar technology
  - Similar challenges in terms of control and protection
- Collaboration with EN/EL
  - Study on AC compensation solutions: **UPFC**



Where are we now?

- ✓ Developing a DC powering scenario compatible with FCC-ee and FCC-hh
- ✓ Comparison with a detailed powering scenario developed with EN/EL

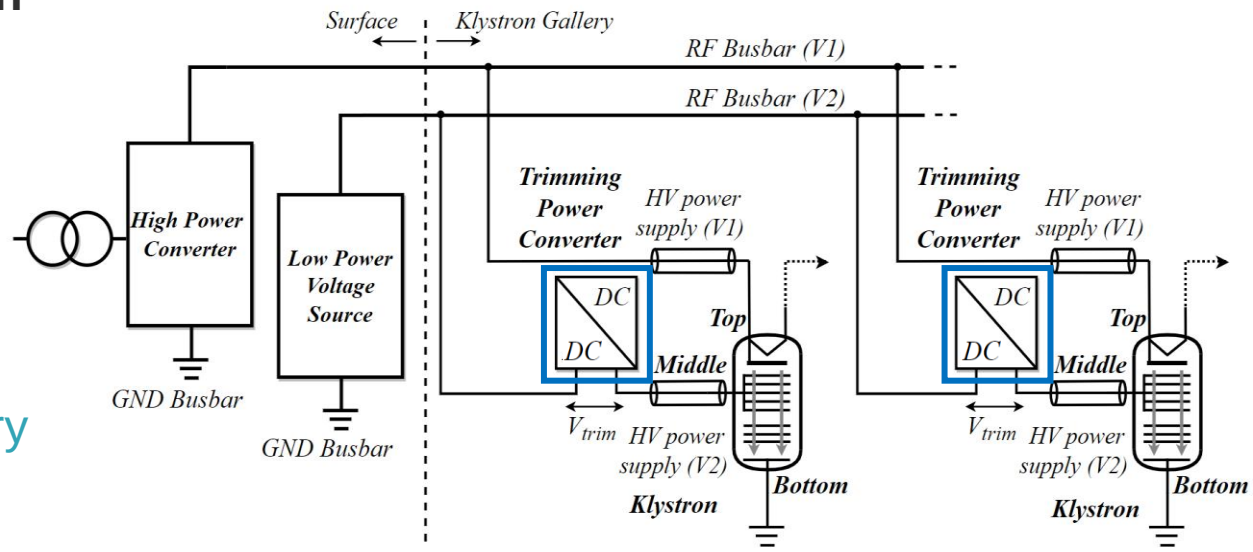
What is missing?

- Industrial partners
- Inputs from industry to better estimate CAPEX and OPEX
- Final comparison and decision→ 2026-2027

Status of the studies: Powering Strategy

Challenge 2: RF Controllability (individual klystron control) and Protection

- Issue: all klystrons “see” the same DC voltage
  - Constraints operation/optimization of the RF
- Solutions for individual klystron trimming
  - Add a small power converter in series with every klystron
  - Change the ration between V1 and V2
- Klystron fault will impact the whole RF System → How to protect the system in case of fault?



Where are we now?

- ✓ Starting a collaboration with Estonian Taltech
- ✓ First studies on trimming converter topologies
- ✓ Series-switch prototype and main converter protection simulations

What is missing?

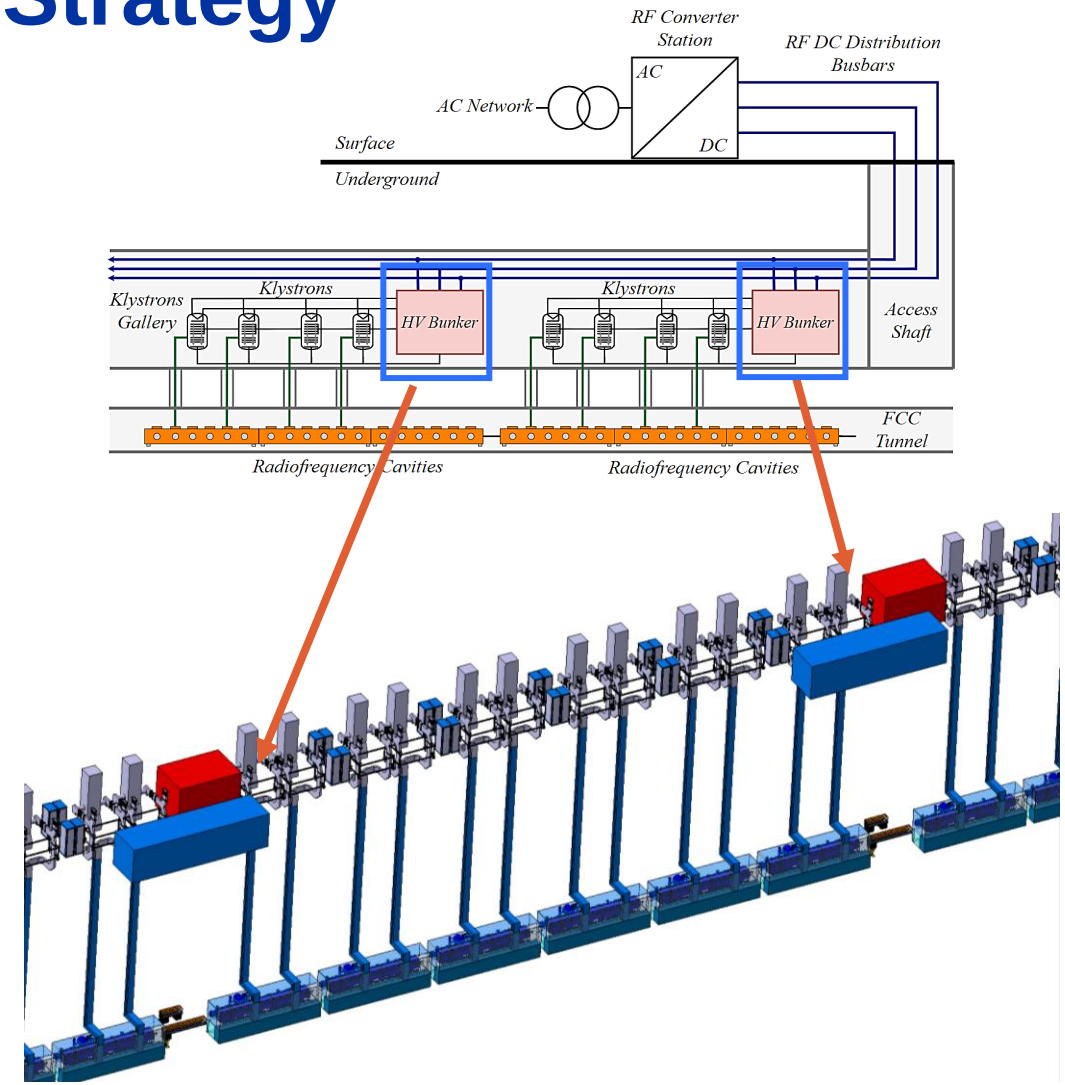
- Klystron specification
- Operation scheme for the RF
- Better understanding the protection requirements of the RF Amplifiers

Status of the studies: Powering Strategy

Challenge 3: Integration of the power converter and HV equipment/switchgear

Integration studies require further details about the RF. Some open points:

- For the HV DC Busbar
  - How to pull the cable through the gallery
  - How to connect the HV bunkers to the DC Line
- For the klystron gallery
  - Space requirements for HV bunkers
  - Integration of trimming PC, solenoids PC, filament heaters…
  - Integration of series protection switches
  - Filter capacitor requirements
  - …



Feasibility study and pre-TDR report

Feasibility Study

- Powering system based on the Modular Multilevel Converter → **Add input from industry (Q4 2024)**
- Definition of requirements with the electrical group → **Network connection requirements (Q4 2024)**
- Initial cost and volume estimation for the Main Converter → **Proposal of an estimated scenario (Q4 2024)**

Pre-TDR Report

- **Align the RF powering with the RF group strategy**
- Significant work needed on integration aspects→ **Fix RF requirements to estimate volumes**
- **Global Optimization strategy for defining the RF powering** → Collaboration with other groups **FROM NOW (if possible)**

Conclusions

- **EPC has demonstrated the feasibility of the powering solution**, based on a single Modular Multilevel Converter supplying a common DC
- **Contacts with industrial partners and universities** initiated to detailed analysis of the solution

Ready

Feasibility Study

- **Collaboration** needed with RF group to define a common strategy and exchange information
- Advance with **integration aspects**, especially regarding integration of equipment within the klystron gallery
- Follow a Global Optimization approach

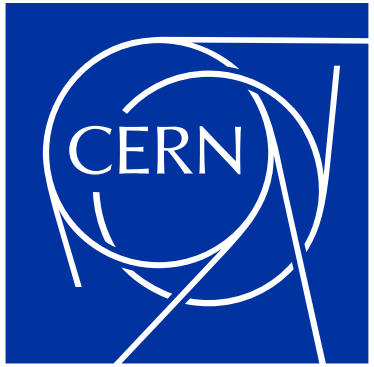
  → Development of CAPEX/OPEX Models

Goal

Detailed RF powering design in 2025/2026

⇩

Pre-TDR Report



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