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DC NETWORKS FOR THE POWERING OF THE FCC

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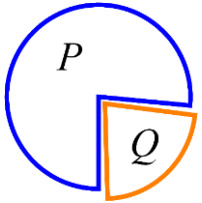
Introduction to DC: Advantages and Challenges

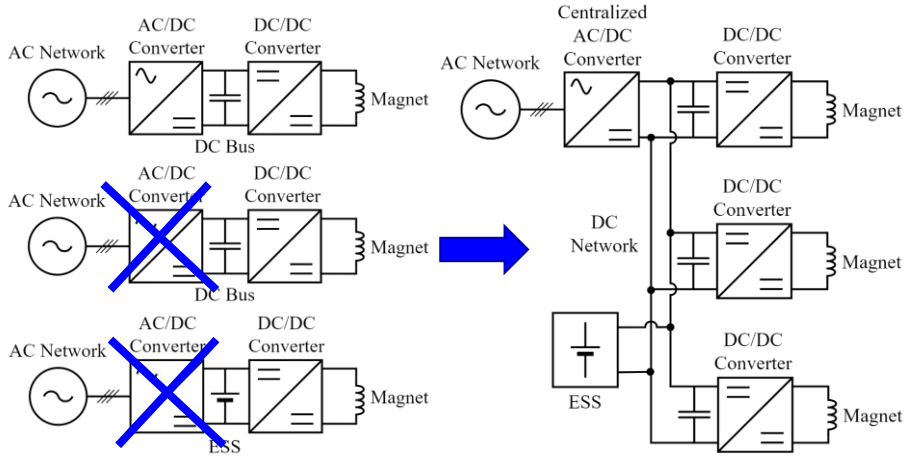
- **No reactive power**
  - Lower transmission constraints
  - Transmission capacity increase



- **Direct integration of DC sources**
  - Reduce converter stages
  - Reduce system footprint

- **Avoid high frequency effects (skin and proximity)**
  - Higher transmission efficiency

DC networks are based on power electronics



DC networks could help to further optimize the FCC electrical network

Introduction to DC: Advantages and Challenges

400 kV → Voltage Conversion → 380 V



HVDC → Voltage Conversion → 380 V

?

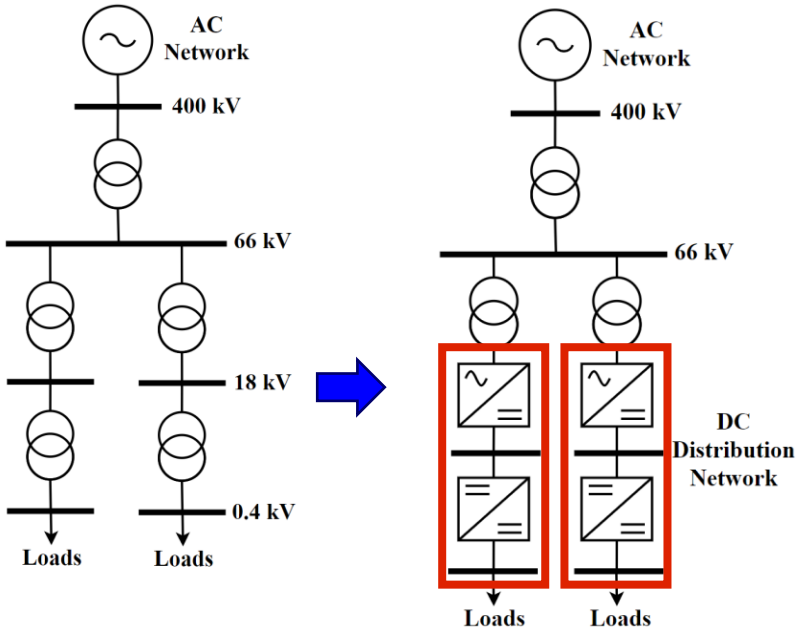
- Voltage conversions are difficult in DC, especially **High Voltage to Low Voltage**
- All power is managed by power converters: **lower reliability**
- Sensitivity to faults is higher in DC: **difficult protection**
- **Two possible uses of DC network:**

RF / High Voltage Transmission ✗ **DC Loads**

Introduction to DC: Network Architectures

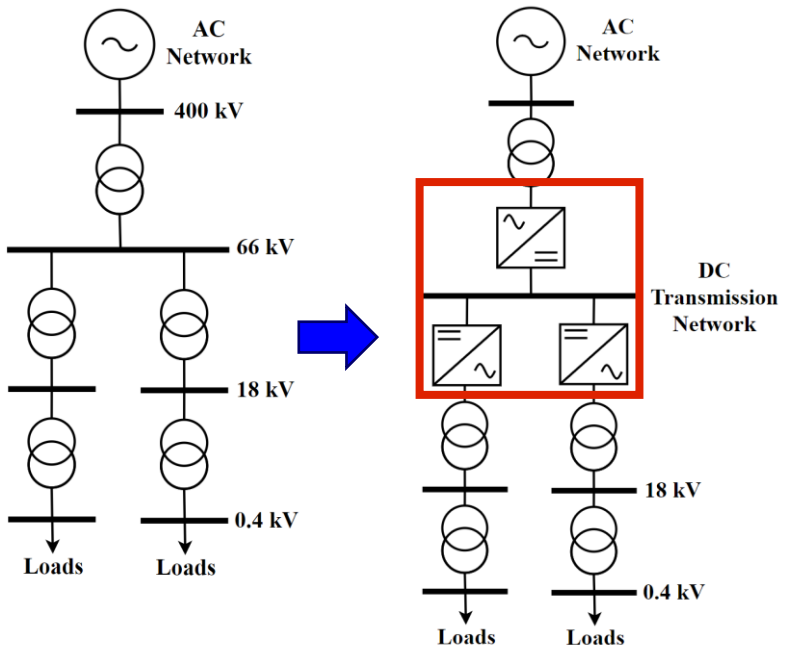
- Two DC network architectures under consideration

A Medium Voltage Local Distribution Network



Use → Supply of DC loads in each FCC access point

A High-Voltage Long-distance Transmission Network

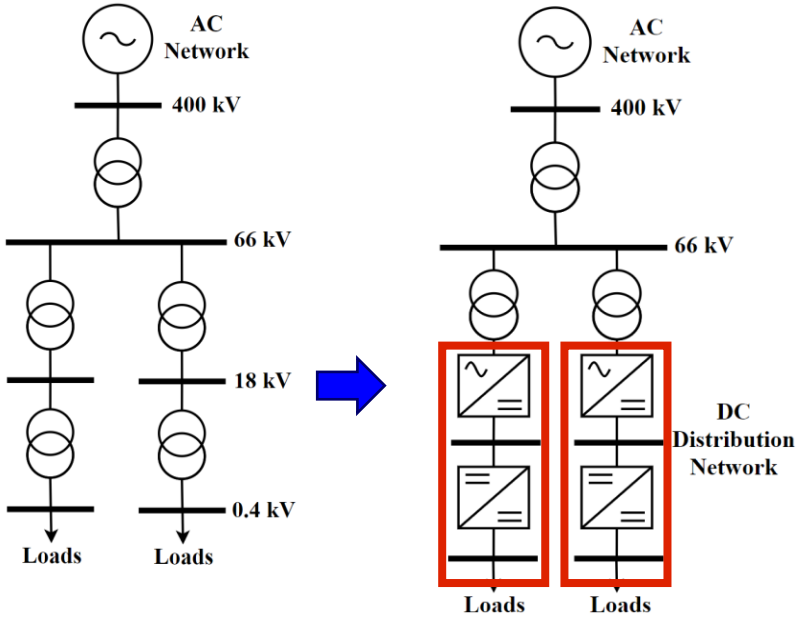


Use → 100 km high-voltage loop as the main supply of FCC access points in AC

Introduction to DC: Network Architectures

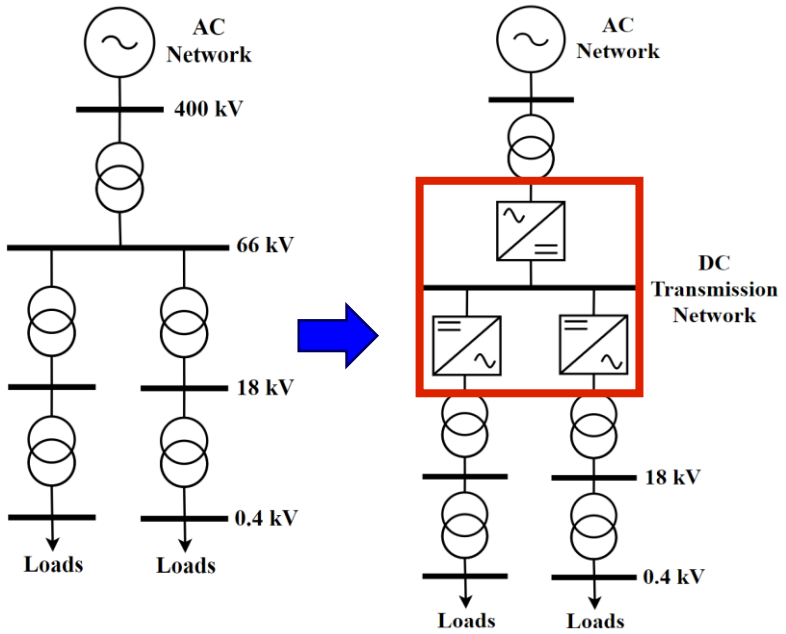
- Two DC network architectures under consideration

A Medium Voltage Local Distribution Network



Addressed by studying how LHC point 2 could be converter to DC

A High-Voltage Long-distance Transmission Network

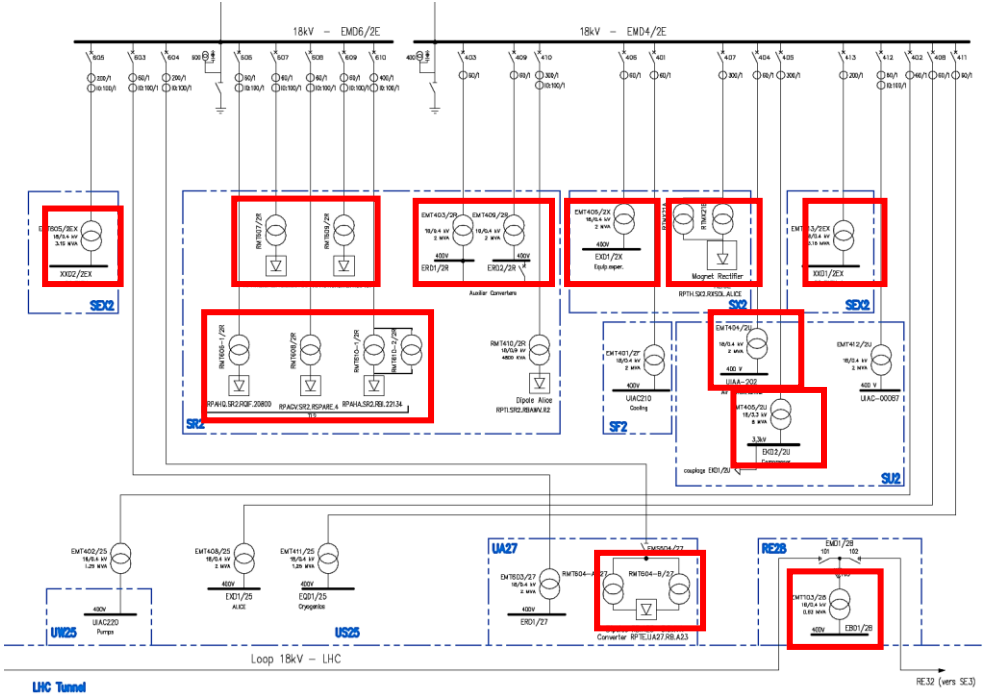


Addressed by CAPEX/OPEX analysis comparing with other AC solutions unders study

Local DC networks: How to improve the existing network using DC

- **The LHC Point 2 AC network has been analyzed and <u>weak points identified in view of the FCC</u>**
- **<u>Issue:</u> Large number of bulky 50 Hz Transformers in AC → <u>Significant impact on required surface</u>**

FCC Network should aim to reduce the footprint required by electrical equipment

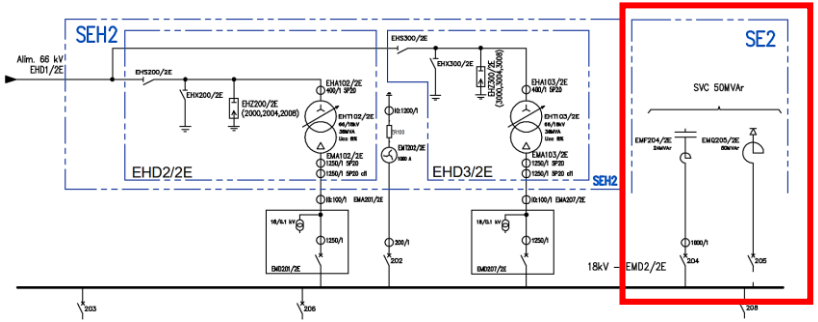


Local DC networks: How to improve the existing network using DC

- **The LHC Point 2 AC network has been analyzed and weak points identified in view of the FCC**
- **Issue: Power quality and inefficiencies issues caused by harmonics and reactive power consumption**

Additional losses caused by reactive power and harmonics→ Impact on energy efficiency

Compensated using Static Var Compensators → Significant impact on required surface



FCC will require new technologies for better managing of reactive power

- **Issue: voltage glitches occur relatively often → Reduction of availability of the machine**

FCC network needs to be robust against network perturbations

Local DC networks: How to improve the existing network using DC

Pros

50 Hz Transformers are replaced by **Solid State Transformers**

- Operated at high-frequency
- High-efficiency
- Compact and more modular

- **Reduction in footprint required by magnetic components**
- **Especially relevant for power converters**

AC/DC Conversion is centralized

- Cost single 2MW AC/DC << Cost 2000x1 kW converter *

- **Potential increased in system efficiency and footprint**

Reactive power issues intrinsically solved with DC grids

- **Less need of compensating equipment**

DC network behaves as a firewall against grid perturbations

- **Better availability of the machine**

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Local DC networks: How to improve the existing network using DC

Cons

AC/DC Rectifiers to be installed

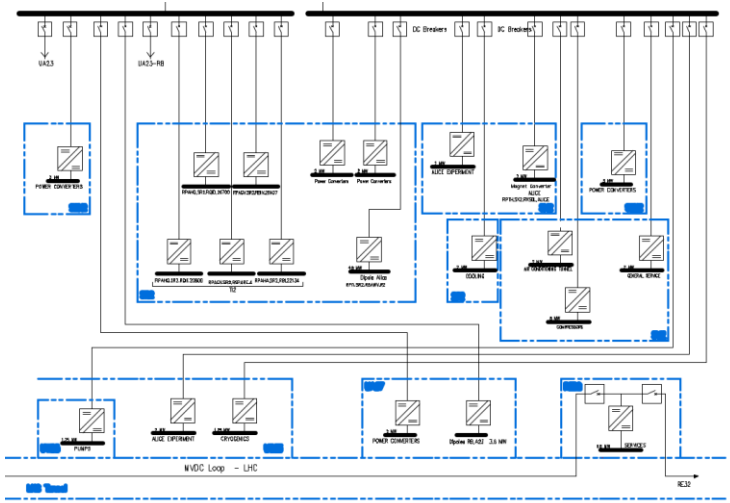
- Space needs to be allocated for these converters

AC breakers are replaced by DC breakers

- More expensive and difficult protection
- Limits interoperability between converters and network
- Still not fully solved

Complexity significantly increases

- Simple transformers are replaced by power converters → maintenance and reliability issues
- Is footprint really improving? → Volume required by converter
- Lack of standardization
  - Voltage levels of loads?
- Triple conversion (AC→DC→AC) for AC loads

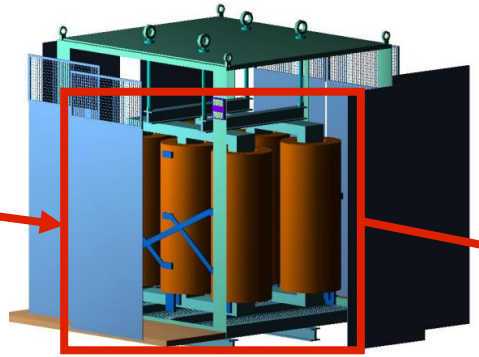


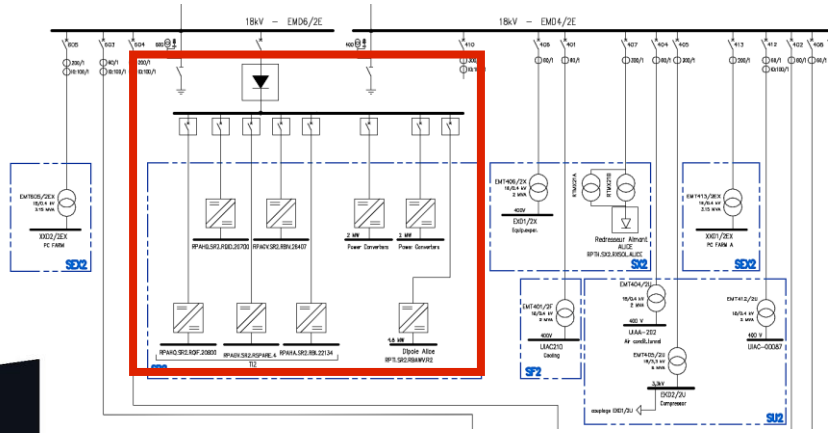
Complete replacement of an AC network by a DC network is not feasible → Focus on converting only to DC certain circuits

Local DC networks: How to improve the existing network using DC

Complete replacement of an AC network by a DC network is not feasible → Focus on converting only to DC certain circuits

➢ **Example: Supplying LHC power converters using DC**





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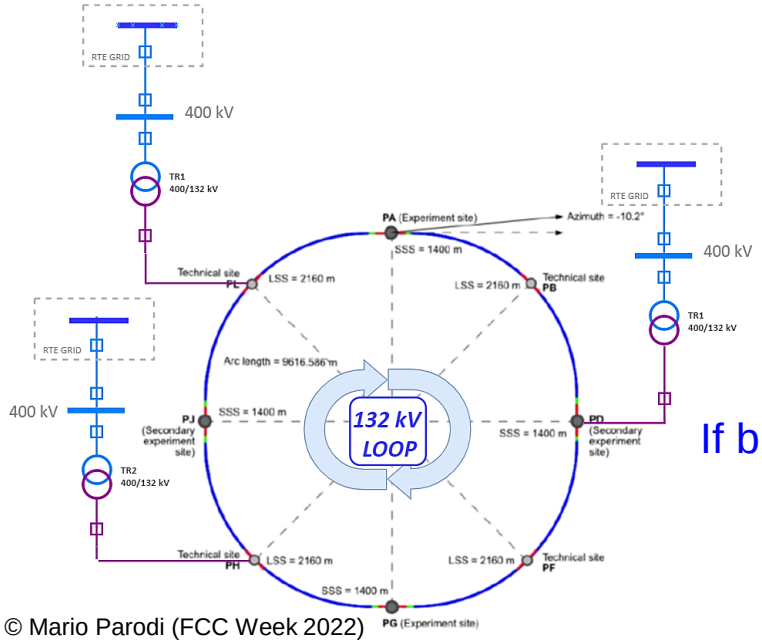
- **Reduction of size of magnetics**
- **Higher modularity and easier repairing**
- **Single AC/DC rectification stage**
- **Rectifier can be used to control AC grid**
- **Efficiency difficult to quantify**

Promissing solution to be further investigated for the design of the FCC Power Converter Alcoves

FCC High-Voltage DC Transmission

DC Networks can be used to transmit power at a larger scale: over the 90 km ring

- **Proposed AC High Voltage Network Scheme**
  - Running through the main tunnel
  - 132 kV and 66 kV options being considered



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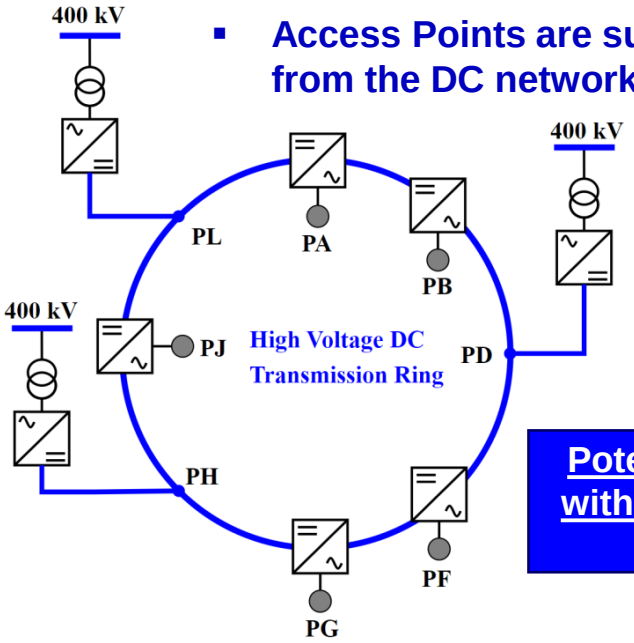
If built in DC



- **Access Points are supplied in AC from the DC network**

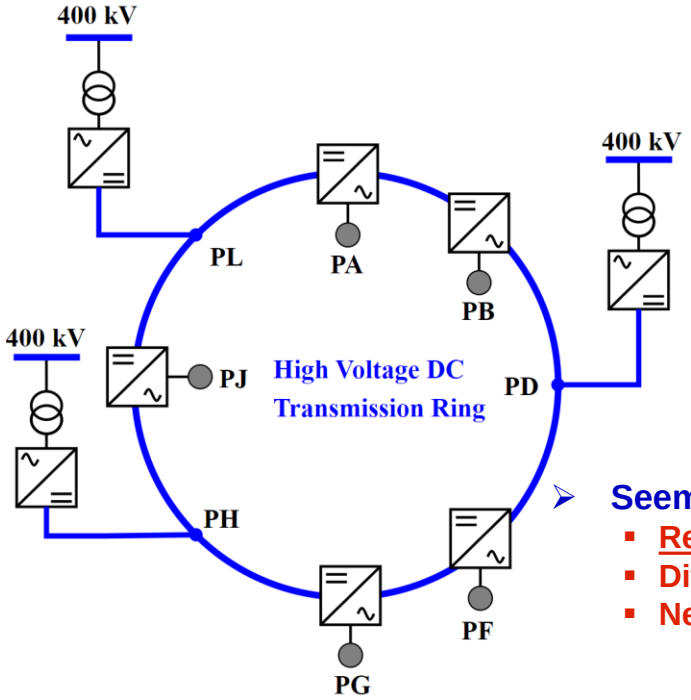
Type of DC network	Purpose	Example
Local	Supply power to loads	LHC Main power converter
Transmission	**Supply power to Access Points**	**Main supply of point H**

Potential benefits with respect to AC solution

FCC High-Voltage Transmission Network

DC Networks can be used to transmit power at a larger scale: over the 90 km ring

Well-stablished conversion technology
- Modular Multilevel Converters
- High-efficiency and reliability



➢ **There is not transmission of reactive power and harmonics through the cable**
- No need of additional compensating systems
- Reduction in the ratings of the 90 km cable

Cost of AC network + **Cost of Compensating equipment** > **Cost of DC Network**

➢ **Controllability of power flows**
- Optimization of network operation

➢ **Seems promising but there are still many questions to address**
- **Realistic cost estimation for DC is difficult due to lack of operational networks**
- **Difficult protection scheme in DC**
- **Need to complete the AC solution scenario to compare with**

Summary of FCC DC Powering Scenarios

➢ Local Distribution in DC

Powering Solution	Advantages	Challenges	Roadmap
Purely AC	Extensive expertise Simplicity	Need of compensating equipment DC loads are not optimized	Better definition of FCC load characteristics CAPEX/OPEX including compensation
Purely DC	Modularity Controllability	High complexity High cost	Abandoned
Mixed AC/DC	Optimization for loads DC to compensate AC	Grouping of DC loads Standardization	Technological feasibility CAPEX/OPEX estimation

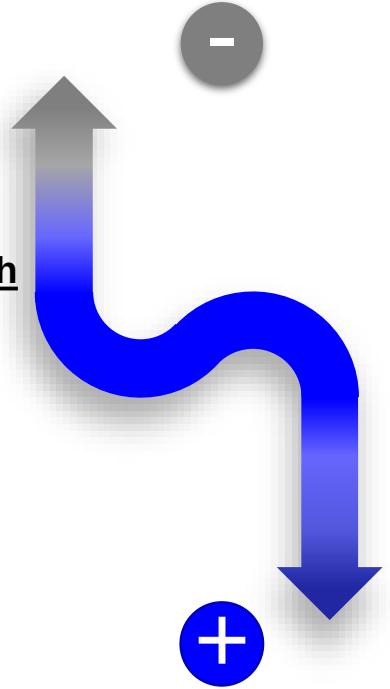
➢ DC for transmission

Powering Solution	Advantages	Challenges	Roadmap
Purely AC	Extensive expertise Simplicity	Need of compensating equipment	Addition of FACTS to models CAPEX/OPEX including compensation
Purely DC	Lower cost of cable Robust to network perturbations Controllability	Higher complexity	CAPEX/OPEX estimation

Work in more detailed models for taking a final decision

Conclusions

- **Local DC Distribution**
  - **An FCC network based on DC technologies is not feasible. Nevertheless…**
  - **Studies performed show advantages when DC is used for supplying very specific equipment → need to define which equipment**
  - **More detailed studies need to be conducted → R&D needed in collaboration with industry.**
- **HVDC Transmission Ring**
  - **Most promising solution: technology available in industry**
  - **A decision can only be made when compared with a detailed AC solution and supported by industrial partners.**
  - **Very important to find collaborations with industry to take a decision in the following years**



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Thank you
for your attention.