Keynote

HVDC Grid Challenges Locks and Opportunities

Power Electronics issues overview

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SuperGrid Institute
Shaping power transmission


pcim
EUROPE
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Introduction : drivers to HVDC

- New requirement due to
- Bulk power long distance (China, Brasil, India)
- Increasing transmission capacity
- Needs to control massive energy flows (congestions avoiding, losses mitigation)
- Power market integration, increase of exhanges
- Increasing the Renewables integration
- Enhancing the solidarity between no synchronized areas
- Off-shore generation integration :more installed power, farer
- High capacity submarine transmission cables
- Stability issues
- Needs for new Ancillary Services provision
- Needs fo more flexibility

Introduction : drivers to HVDC

- **Limitations of the classical HVAC system**
  - Impossibility to connect no synchronized AC Grids with different Frequencies
  - Possibly large inter area oscillations when connecting two AC grids with same Frequencies and Voltages
  - Limited distances due to :
    - **Inductive behavior of overhead lines**
    - **Capacitive behavior of cables**
  - The power flows are guided by the minimum impedance paths

- **Conclusion : the previous requirements cannot be addressed**

Introduction : drivers to HVDC

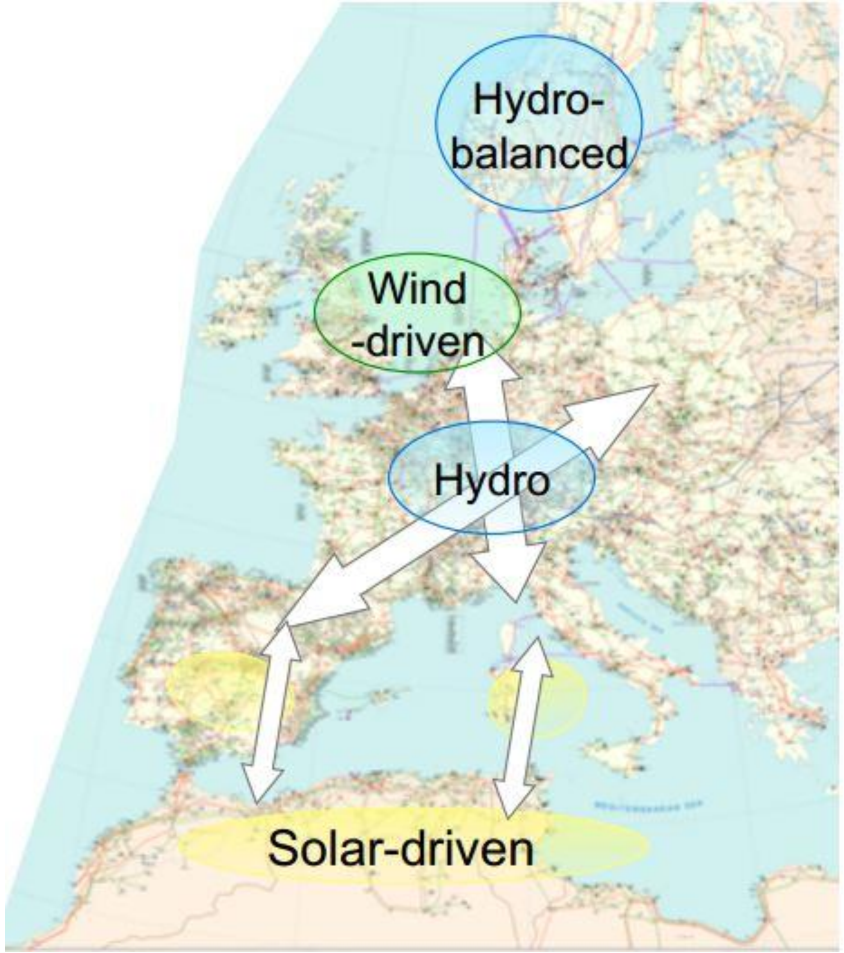
Solutions :

1. Actual HVAC system reinforcement by:

- Adding new overhead lines
- Using widely FACTS systems

2. Building in parallel a new HVDC System

3. Hybridation

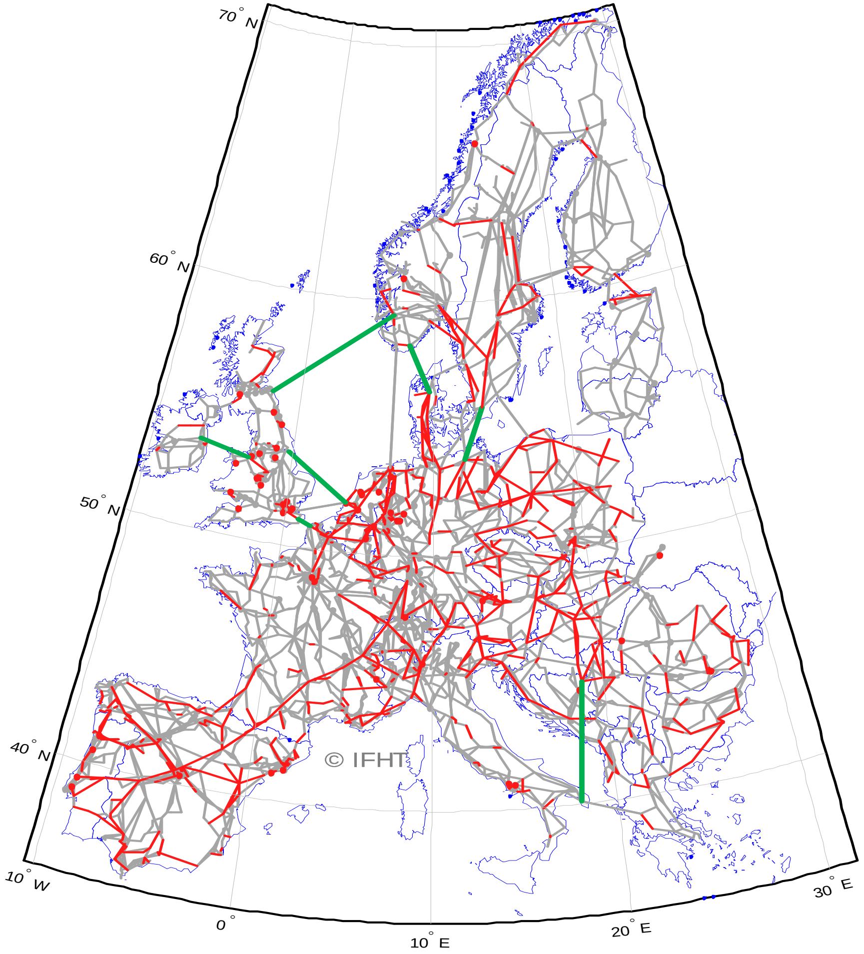


Source B. Jacobson Développements in Multiterminal HVDC , IEEE EPEC , Winnipeg , Manitoba , Oct 11, 2011

Introduction : drivers to HVDC

Existing line
New HVAC
New HVDC

HVAC + FACTS Solution

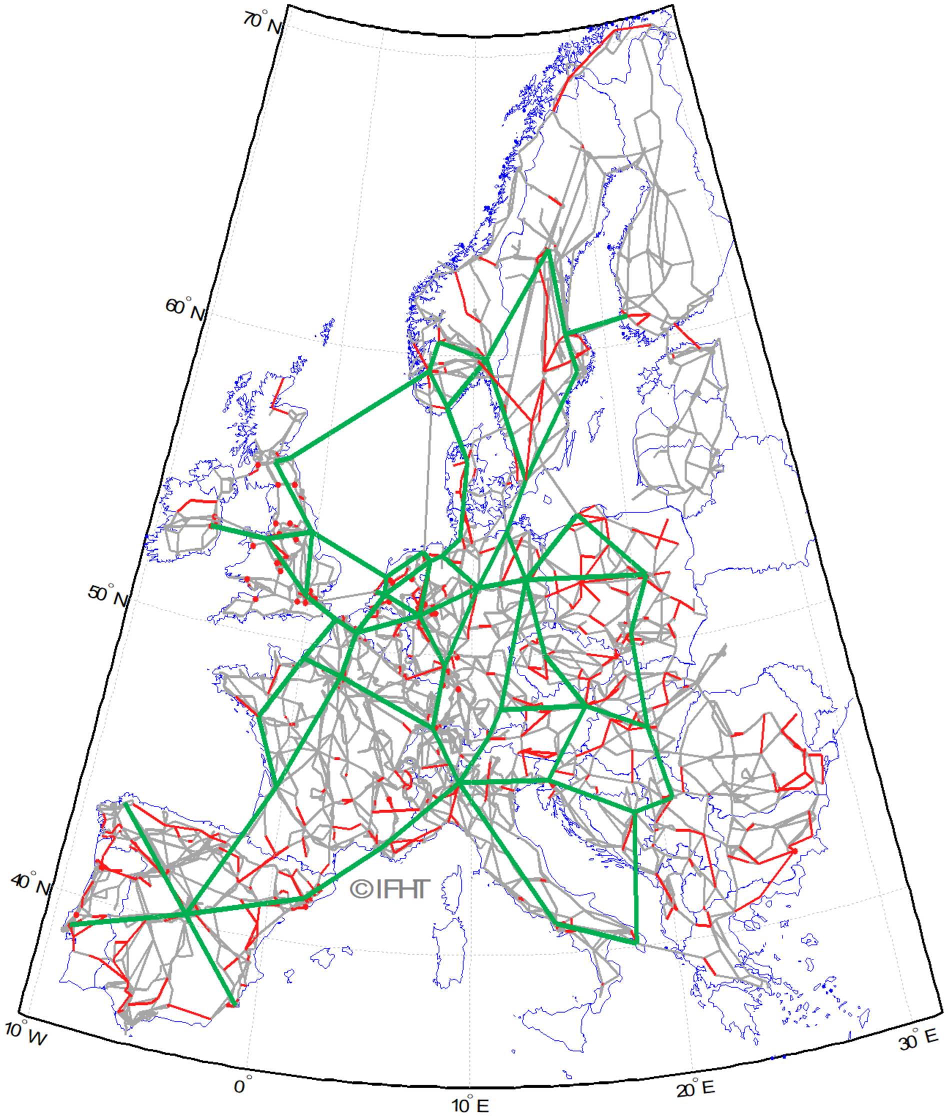


From IRENE 40.eu
Future European Energy Network 7FP

Introduction : drivers to HVDC

HVDC Solution

Existing line
New HVAC
New HVDC



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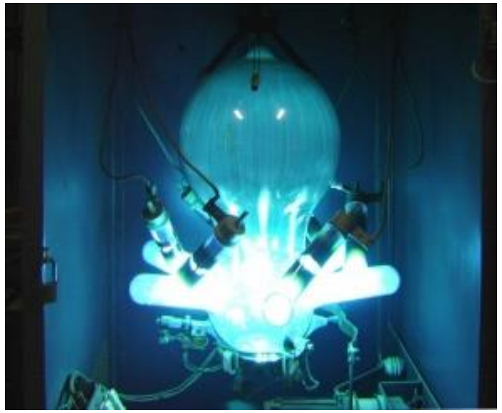
Some historic facts and some achievements

- mercury-arc valve 1901
- First HVDC Project Gotland 1 in Sweden 1954 : Submarine cable , mercury-arc valves , 30 MW , 150 kV
- Last built : 1972 Nelson River 1 plant (Manitoba) 150 kV, 1800 A
- Last in operation : 8/2012 : HVDC Inter_Island , New Zeland



Images for wikipedia

Some historic facts and some achievements

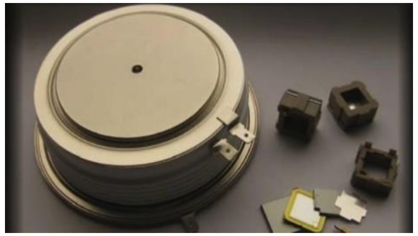
- **Thyristor « Silicon Controlled Rectifier (SCR) by W. Shockley ,1950**
- **First built : Back to Back plant Eel River (Canada) , +/- 80kV, 320 MW, 2kA , 4800 thyristors (1972) Upgraded 2014**

- **Ongoing technology. Example of Jinping-Sunan Line**
  - Commissioned in 2013
  - LCC Technology, 7200 MW , ±800 kV, 2090 km

Images for wikipedia

Some historic facts and some achievements

1200 A / 3300 V



285 A / 6500 V

- IGBT : Insulated Gate Bipolar Transistor , 1978-1979
- Ex : INELFE (INterconnexion ELectrique France-Espagne)
  - 2* 1000 MW; +/- 320 kV, cables
  - MMC converter

- http://www.inelfe.eu/IMG/pdf/Spain_France_electrical_interconnection_ENG-compressed.pdf

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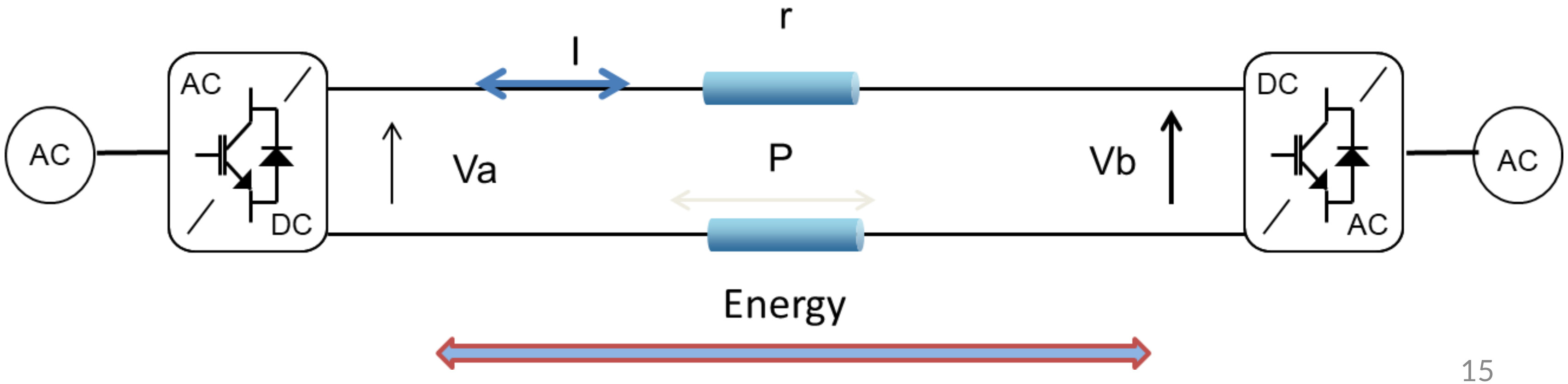
HVAC vs HVDC (not exhaustive)

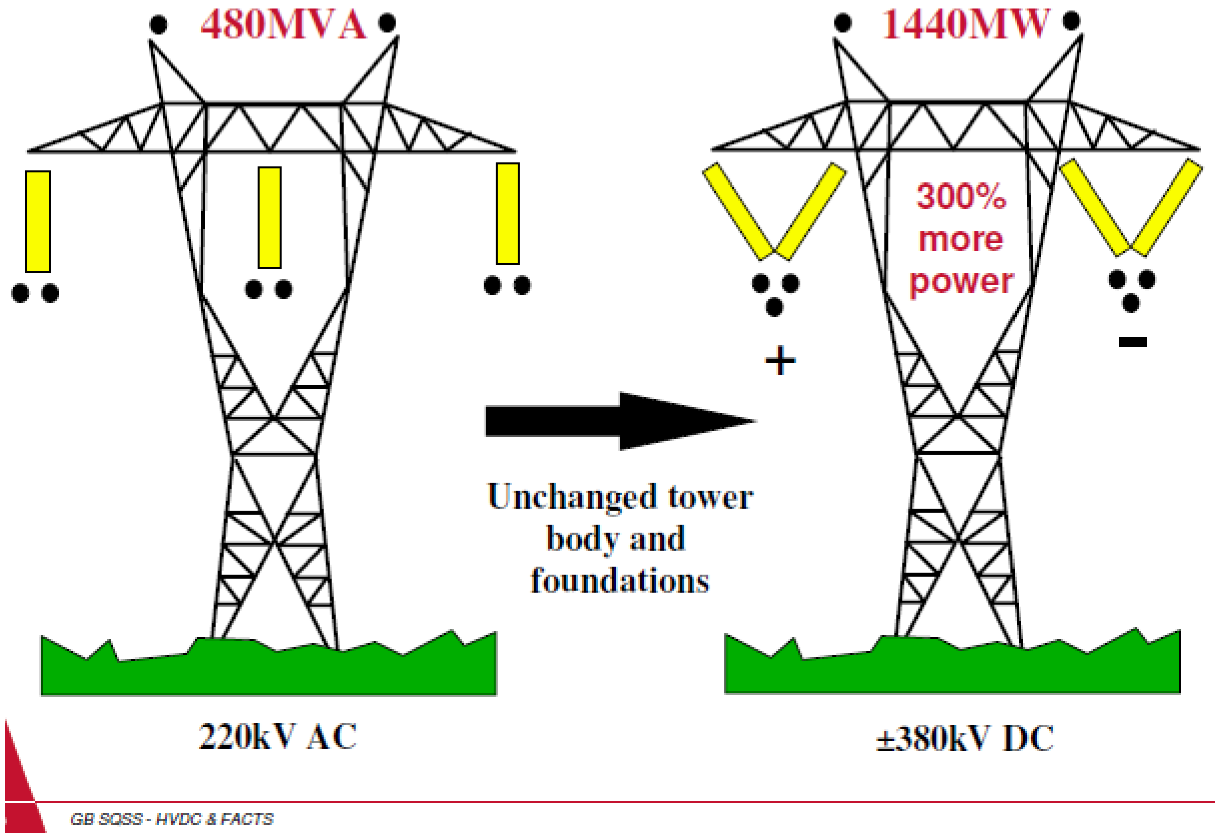
- **Limitations of the classical HVAC system**
  - Impossibility to connect no synchronized AC Grids with different Frequencies/voltages
  - Impossibility to control the power flows
- **HVDC**
  - Fast control
  - Coupling AC grids
  - Power flow controls



HVAC vs HVDC (not exhaustive)

- **Limitations of the classical HVAC system**
  - Limited distances and capacity due to :
  - Inductive/capacitive behavior of overhead lines
  - Capacitive behavior of cables

- **HVDC**
  - No impedance effect
  - Possibility to use cables for long distances power transmission



HVAC vs HVDC (not exhaustive)

- **However HVDC requires :**
  - Special protection system, including Breakers and Surge Arresters
  - More CAPEX due to the conversion systems
  - More losses
  - Special AC Filters and Reactive Power compensation (LCC technology)
  - To be integrated on an existing system with dedicated rules and operation (Interoperability)
  - To fulfill with existing standards an new ones (some of them are not stabilized)
  - To pay attention to the Short Circuit Ration decrease....

HVAC vs HVDC (not exhaustive)

- Off course , the HVDC power electronics can provide huge advantages by using the converters capabilities (FACTS functions, Disturbance decoupling , contributions to ancillary services ,...

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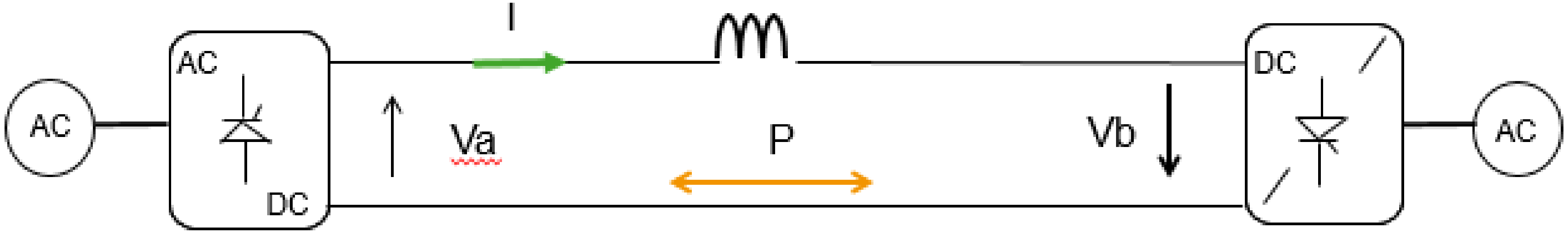
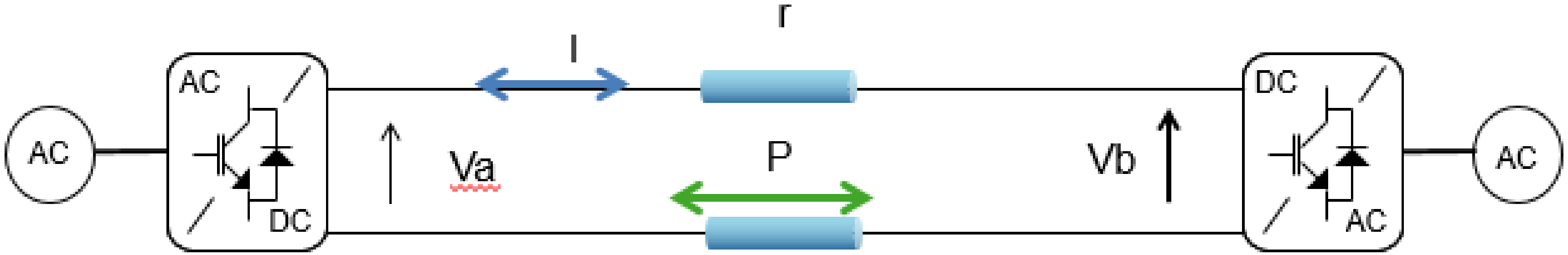
LCC vs VSC

Two Power Electronics conversion systems

LCC : Line-commutated converters



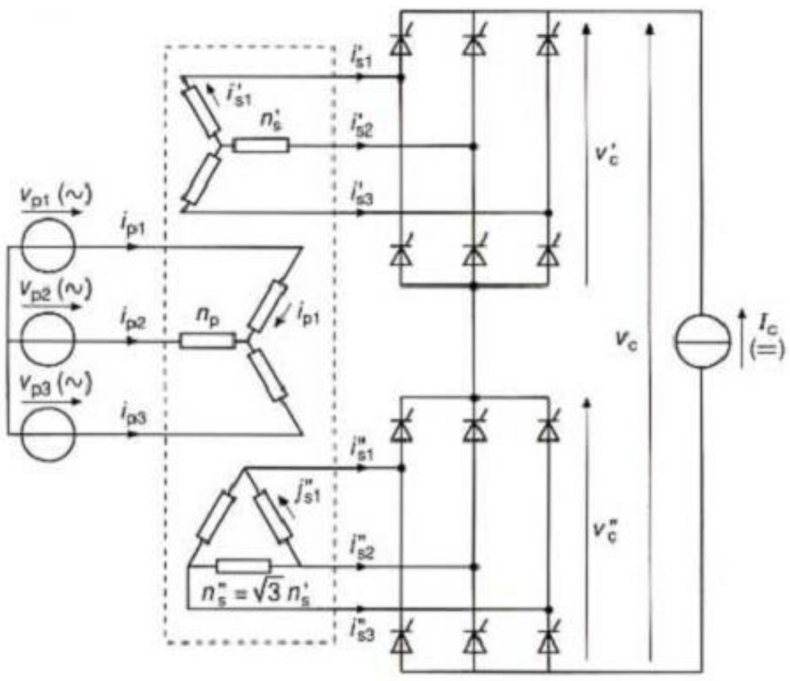
VSC : Voltage Source Converter

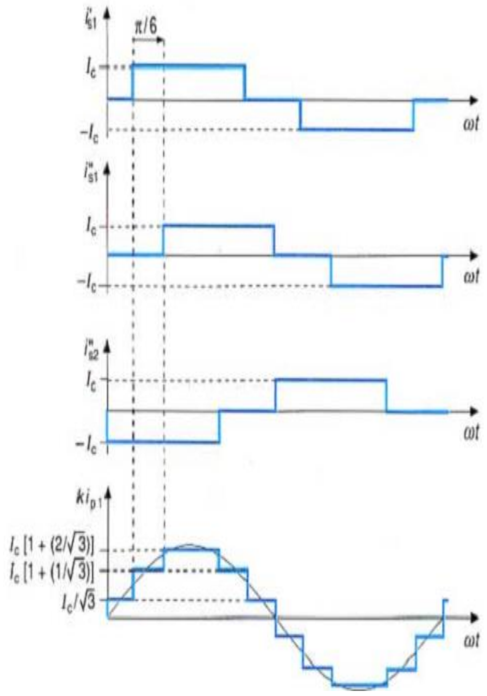


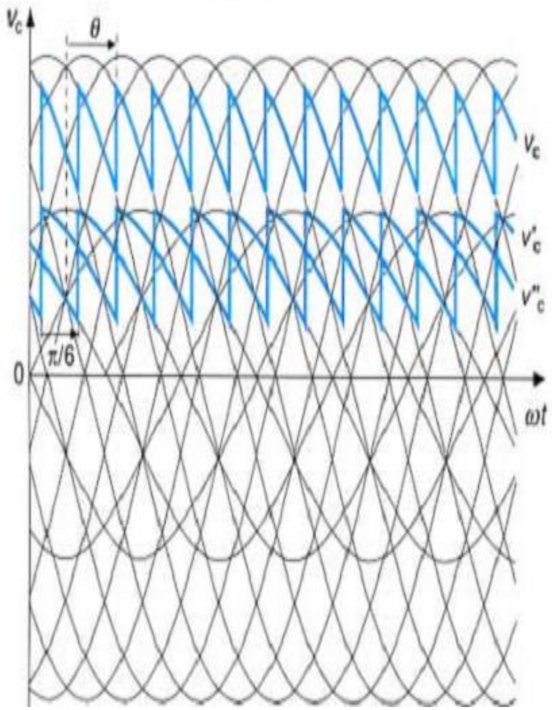
LCC vs VSC

Thystor based technology

...At the beginning : the LCC







Source : Techniques de l’ingénieur

LCC vs VSC

LCC some issues

- The Reactive Power consumption vs Active Power transmission
- Necessity of reactive power compensation
- Low frequency harmonics, must be filtered

- The energy transit control is done by the action on the firing angles
- Two degrees of freedom (the two control angles)
- To avoid the inverter loss control its firing angle q is limited between 90° to 150°
- The overlapping phenomenon have to be considered
- The reversibility is not easy (the current is unidirectionnal and changing the voltage sign…).
- Not adapted for grid forming
- Not adapted for DC Meshed grids.

BUT : CHEAPER and MATURE TECHNOLOGY

LCC vs VSC

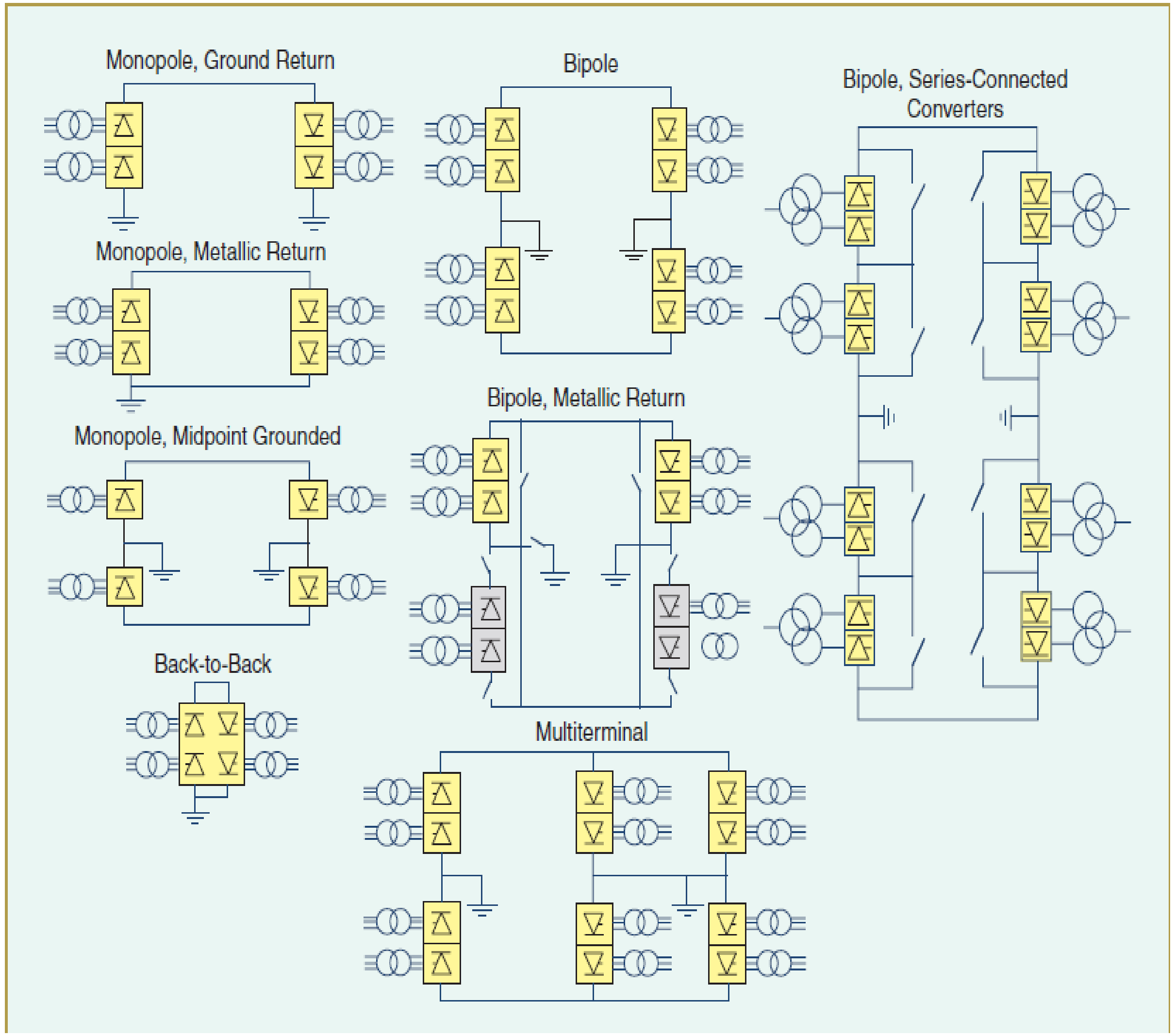
The LCC Based HVDC links

Monopole , ground return :

The power is transmitted from one converter station to another station through one conductor (positive or negative polarity) and return is grounded at both stations
Monopole , metalic return : the same but through one conductor and metallic conductor is used as return and grounded at one end

Bipolar : Both poles transmit a power in same direction. It is grounded at both stations. Both poles are operating at equal currents during steady state, therefore zero current through the ground. It can be operating as a single pole during fault at another pole

Back to back : The LCCs are located at the same area , suitable for connecting no synchronous area



Source : The ABC's of HVDC Transmission Technologies , M.P. Bahrman et al, IEEE Power and energy Magazine 2007

LCC vs VSC

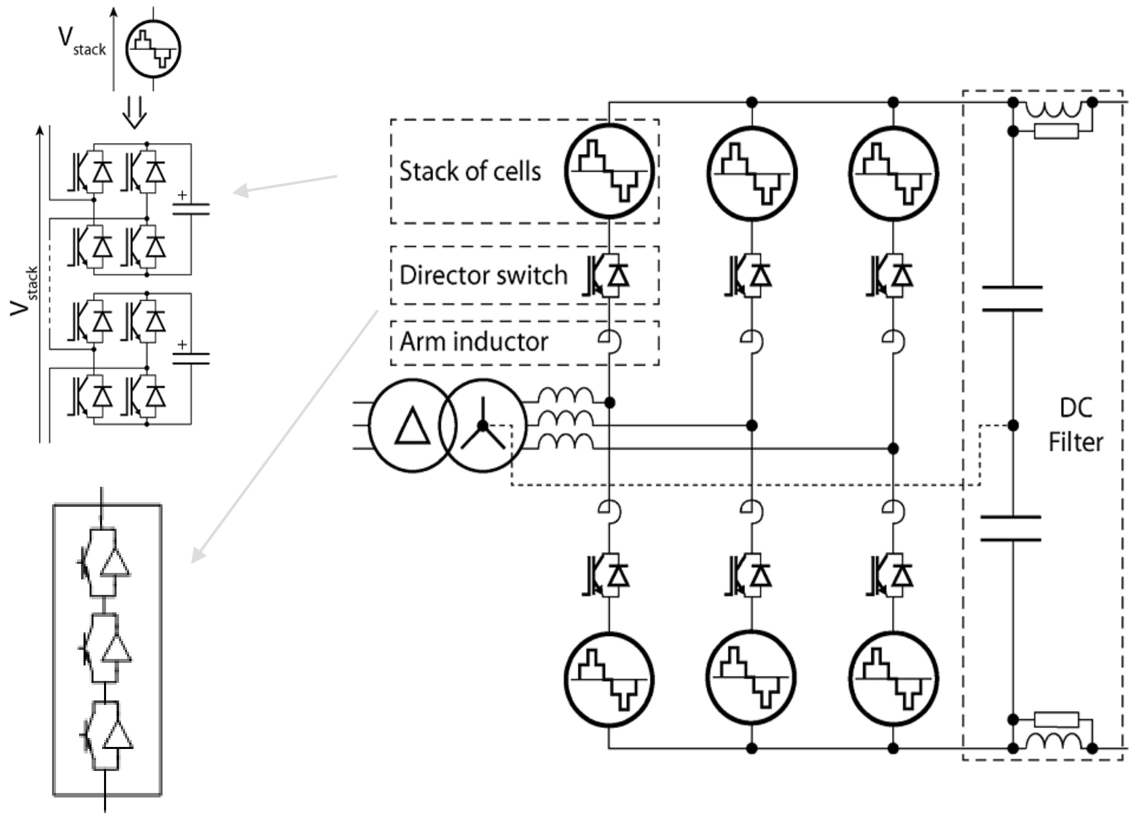
Transistor based technology

... The rising technology

With only three drawbacks : more CAPEX/OPEX*, more losses , less return of experience

The architectures are based on the components association and/or modules associations (ex of Aternate Arm Converter

*** The CAPEX and OPEX are disputable**



LCC vs VSC

The MMC : the Army Swiss Knife!

Clean waveforms

Low sub modules frequency operation

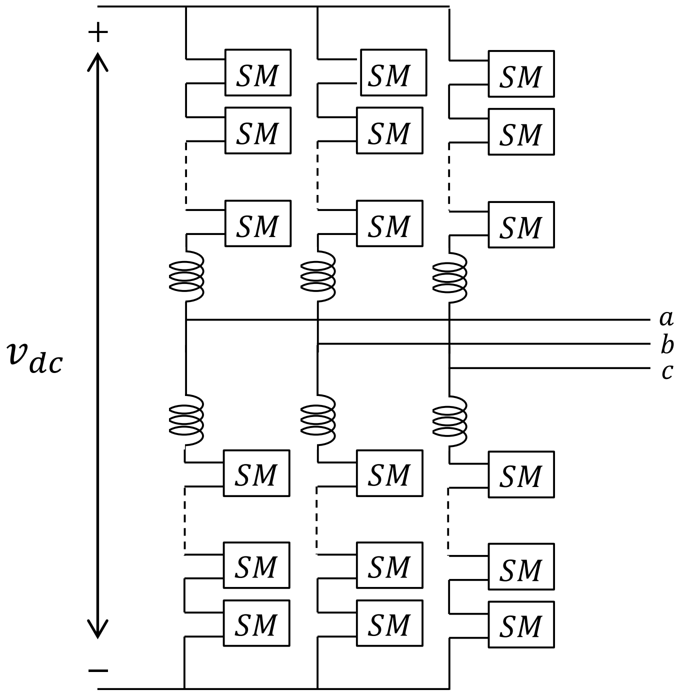
No theoretical limits for Voltage/Power ratings

Internal storage possible exploitation

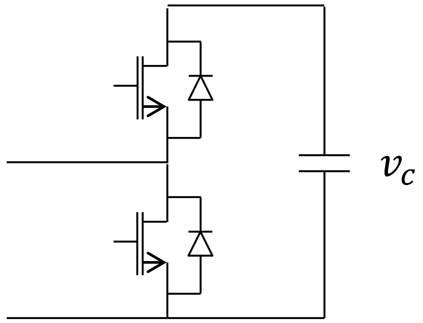
DC/AC disturbances damping

The use as a FACTS for AC benefits

Stability issues purpose



Topology of 3-phase MMC

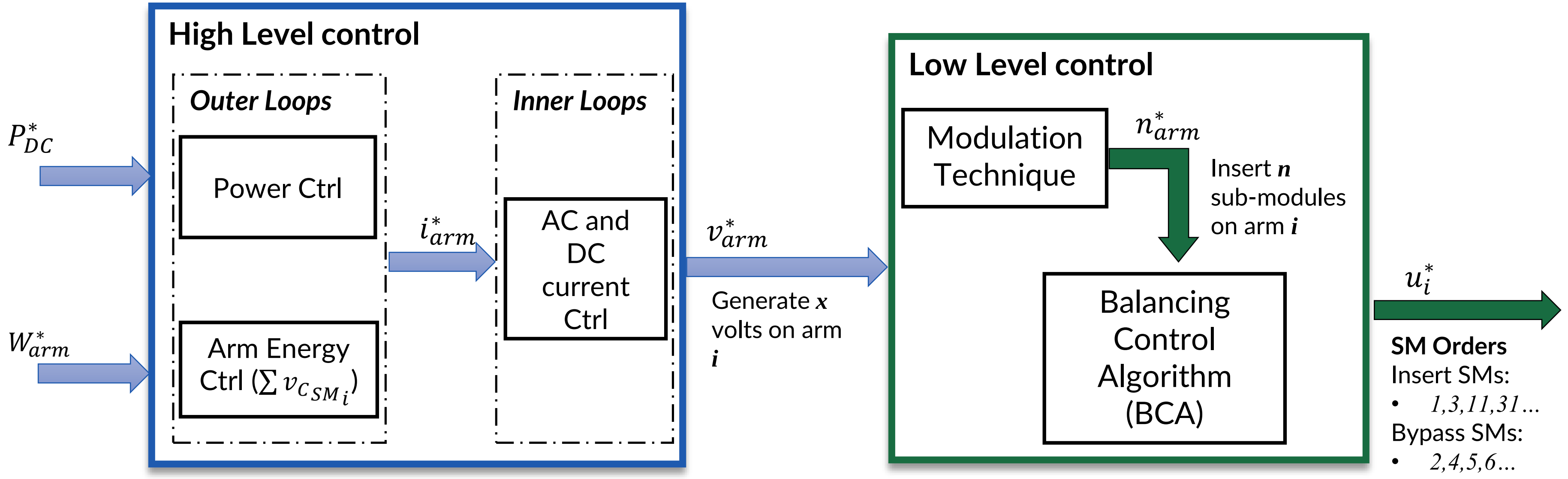


MMC sub module

LCC vs VSC

The MMC control is a little bit more complex due to : modules and internal energy balancing

- **Main control objectives:**
  - Control the power flow to the grid
  - Control the converter energy balance ($P_{AC\,arm} = P_{DC\,arm}$ on each arm)
  - Control DC and AC current circulation
  - Keep the individual SM capacitor voltages balanced (balancing algorithm)



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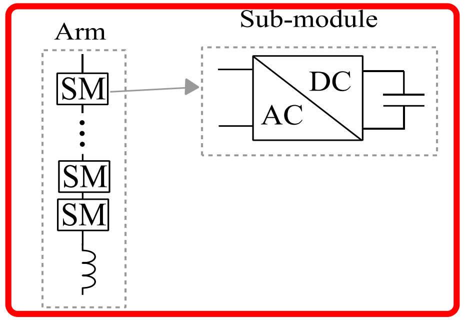
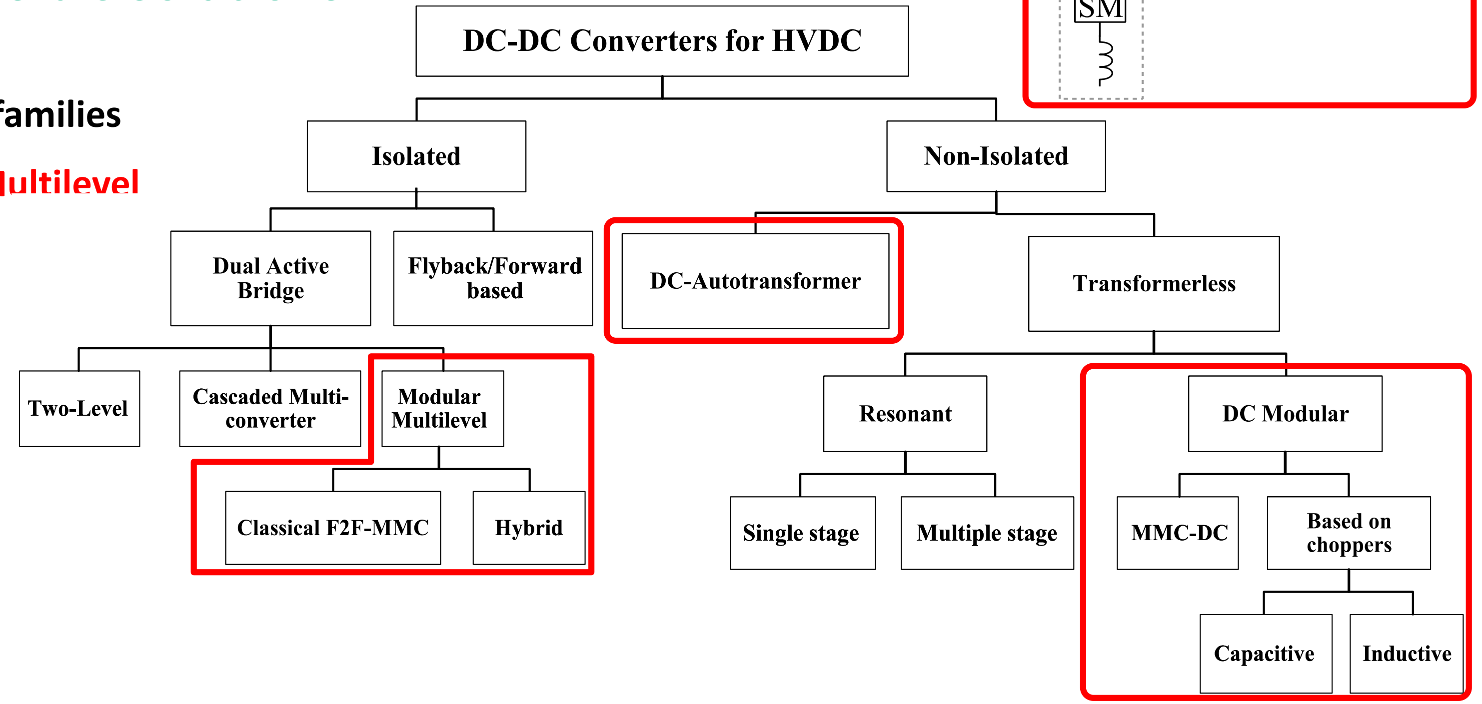
DC/DC

- Another way to mesh the point to point HVDC transmission system is to create DC/DC links between
- There is a large field of possible solutions
  - Classification by circuit families
  - Main trend: Modular Multilevel Structures

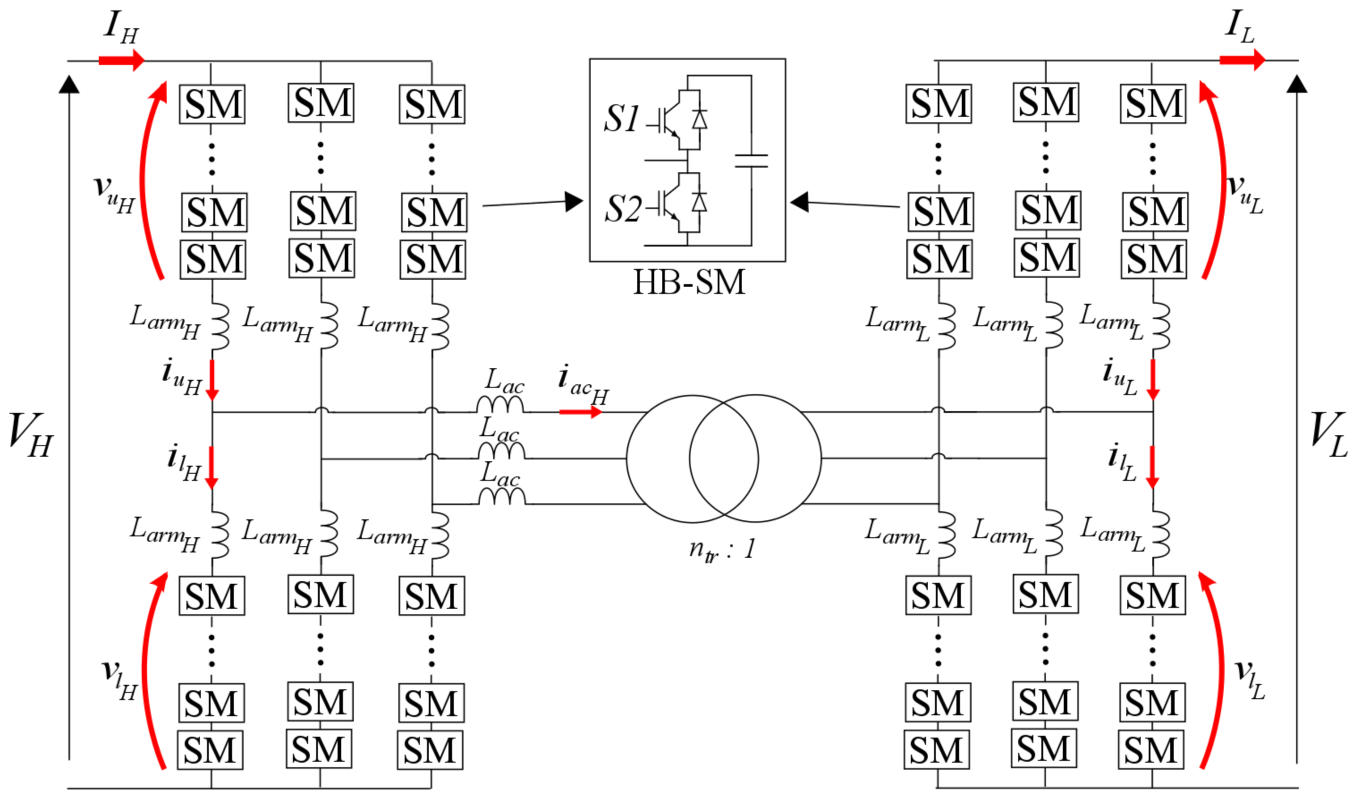




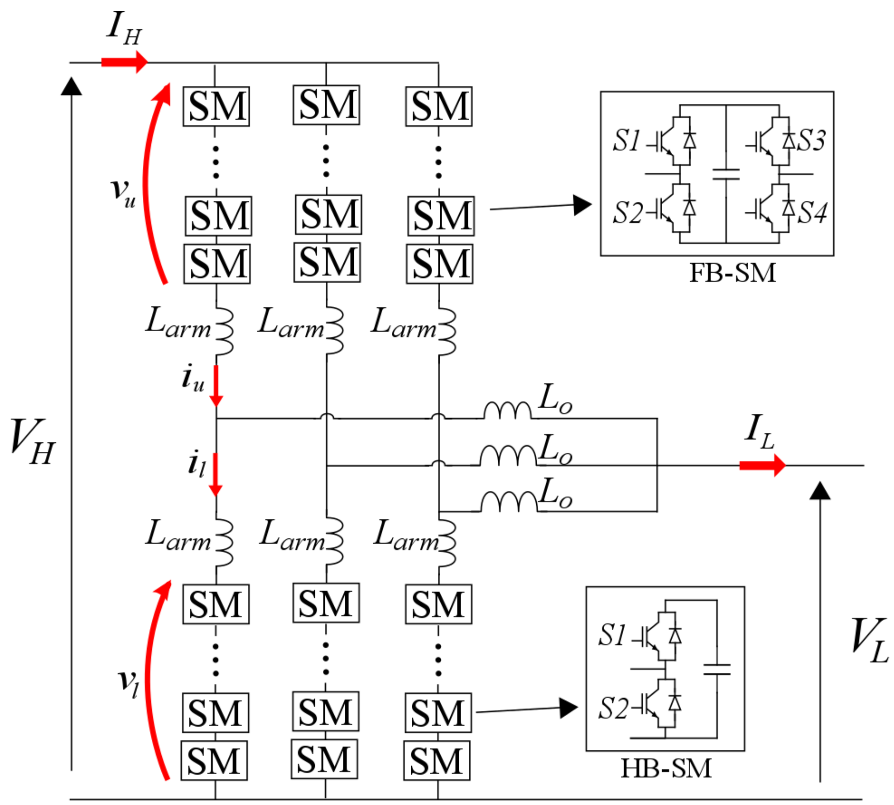
DC/DC

Two MMC based DC/DC HVDC converters

Front-to-front MMC (F2F-MMC) Could be isolated or not



DC- MMC (close to chopper framework)



**Three phases are considered as example but both circuits can operate with different number of phases*

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DC breakers

- These devices are included in the presentation due to the very important role of Power Electronics as a necessary component
- Contrary to AC currents, there is no zero cross over of the fault current
- In consequence it is necessary to extinguish this current directly via special switches of by creating a deviation via an oscillating circuit (current deviation or reverse voltage imposition)
- Two kind of PE switches are used ; Thyristors and IGBTs
- These circuits can be placed in series or in parallel
- Usually are associated with Mechanical Switches

DC breakers

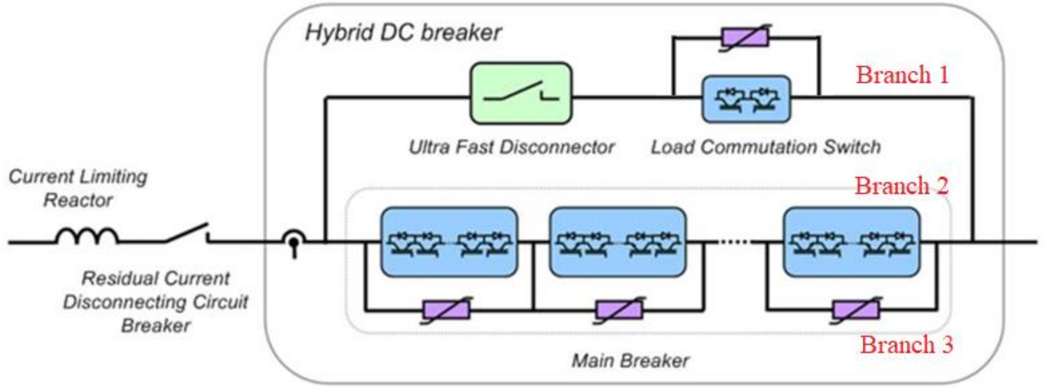
DC Breakers a classification attempt

- DCCB
  - Mechanical Disconnector (MD) base
    - Commutation of faulty current
      - inverse voltage implementation in Series with MD
        - Constant volateg
          - Arrester
        - Transient voltage
          - LC circuit
      - inverse voltage implementation in parallel with MD
      - current ~~pulse~~ injection/generation/creation in parallel with MD
      - Semiconductor in series with MD
    - Non-commutation
      - Current injection in series with MD
  - Solid state breaker
    - Using semiconductors
      - Opening of semiconductors

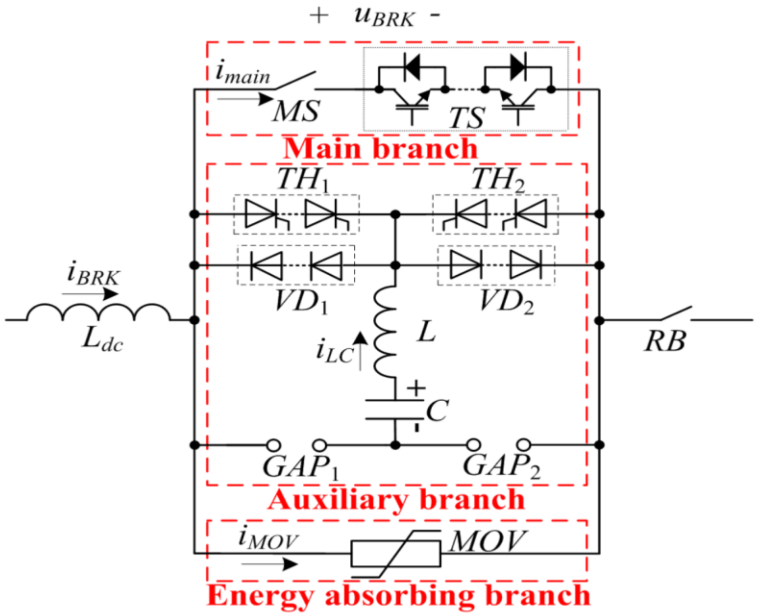
DC breakers

DC Breakers examples

ABB Model : based on energy dissipation



Inverse voltage implementation vis an oscillating circuit



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Conclusion : Some locks and research trends

- **General lock : lack of return of experience for modern technologies**
- **Operation**
  - DC/AC interaction mastering
  - New ancillary services
  - Losses mitigation
  - Interoperability with the existent system
  - Very rapid modes to face
- **Technology**
  - New components integration
  - HVDC Breakers
  - HVDC Cables
  - HVDC insulation and earthing
  - Measurements ,sensors
  - CAPEX, OPEX reduction

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Thank you!

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