Multilevel Modular Converters (MMC)

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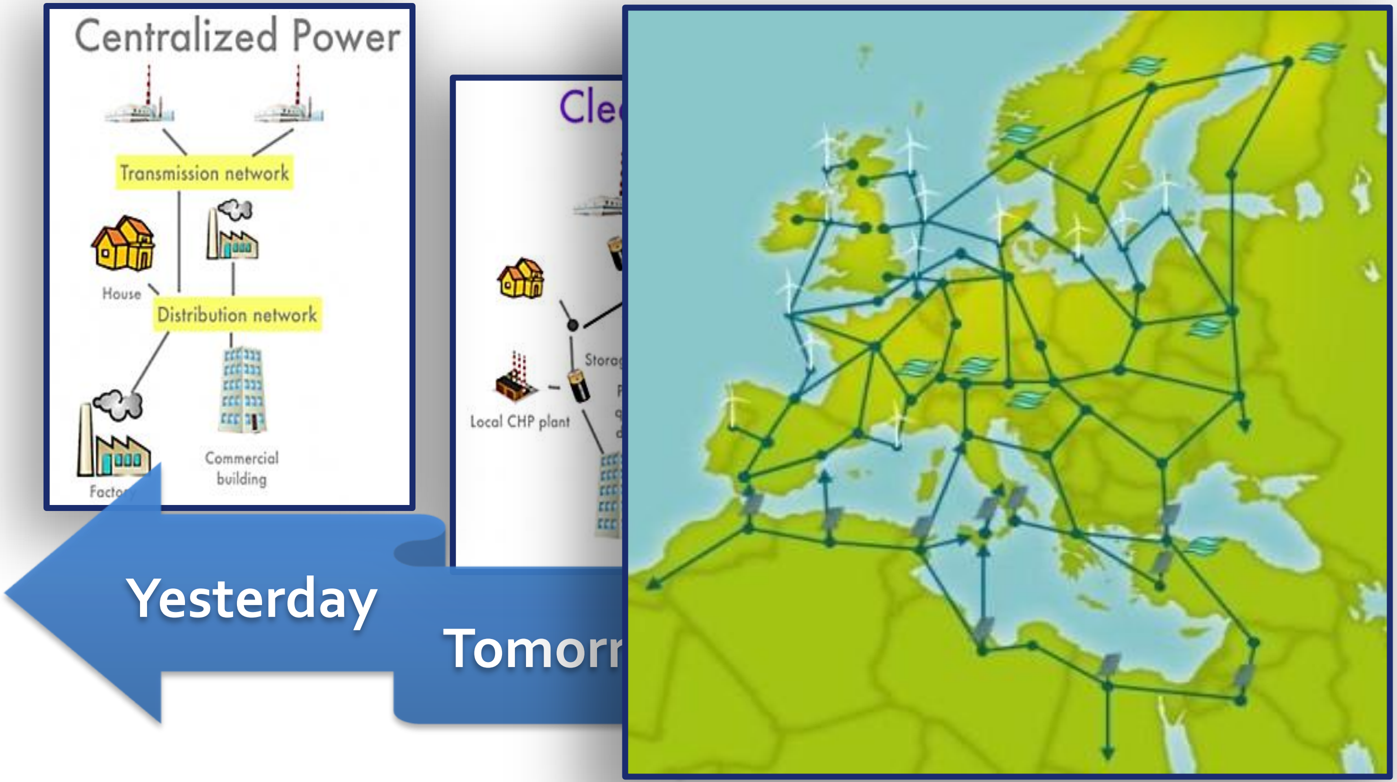
Outline

- Introduction
- HVDC Stations
- Need for MMC
- Current Practice
- MMC Design Choices
- MMC Basics
- Control Structure
- Challenges in HVDC Grids
- System Integration
- Fault Response

Introduction



Adapted from: http://www.ilsr.org

Source: Friends of Supergrid

HVDC Stations

HVDC Classic

Source: ABB

VSC-HVDC

Source: Siemens

Need for Multilevel Converters

- Two-level and diode-clamped topologies are suitable for medium voltage.
- But:
  - Redundancy difficult to achieve.
  - Scale poorly to many levels.
  - Trade-off between switching losses and harmonic performance becomes critical for MV and HV converters.

Multilevel converters are needed!

Current Practice

MMC-HVDC

Offshore wind-power plant (OWPP) connection projects

Project	Capacity (MW)	DC-link Voltage (kV)	Supplier
Borwin Beta	800	± 300	Siemens
Borwin Gamma	900	± 320	Siemens
Dolwin Alpha	800	± 320	ABB
Dolwin Beta	916	± 320	ABB
Dolwin Gamma	900	± 320	GE
Helwin Alpha	576	± 250	Siemens
Helwin Beta	690	± 320	Siemens
Sylwin Alpha	864	± 320	Siemens

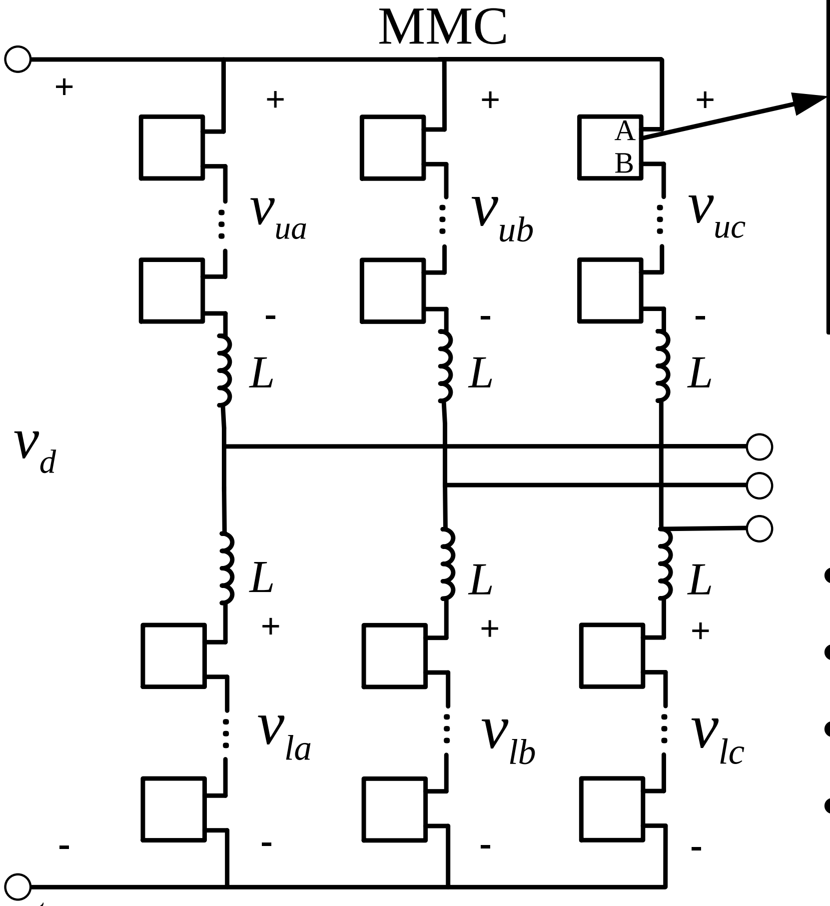
Current Practice

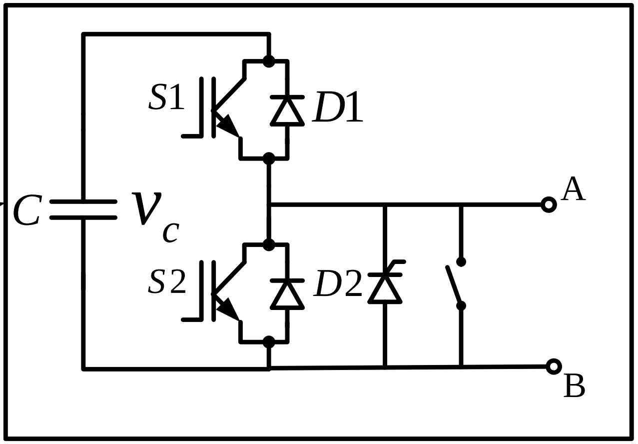
MMC-HVDC

Interconnectors

Project	Capacity (MW)	DC-link Voltage (kV)	Supplier
Trans Bay Cable	400	± 200	Siemens
INELFE	2000	± 320	Siemens
NordBalt	700	± 300	ABB
Skaggerrak 4	700	500	ABB
SydVästlänken	2 x 600	± 300	GE
COBRAcable	700	± 320	Siemens
ElecLink	1000	± 320	-
Nemo Link	1000	400	Siemens
Viking Link	1400	-	-

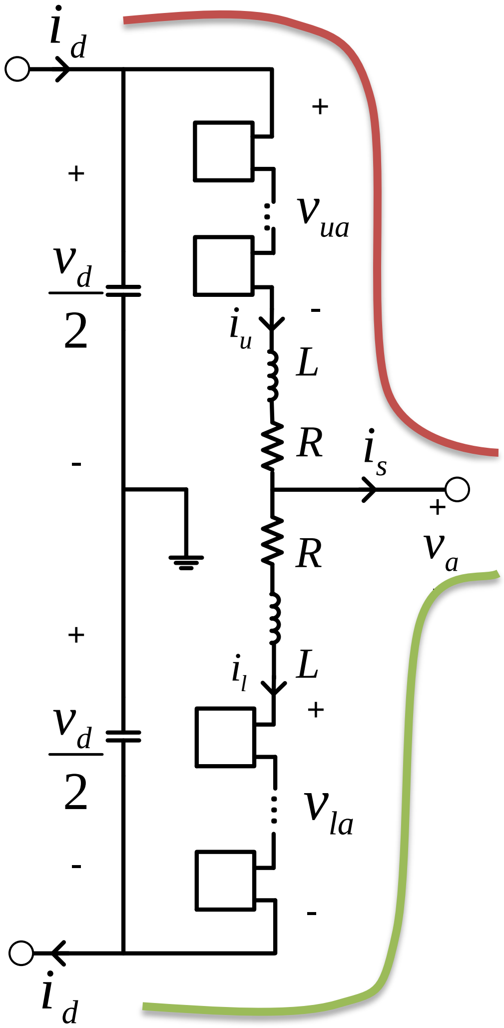
MMC design choices





- Choice of semiconductor devices
- Choice of number of submodules (N)
- Choice of submodule capacitance (C)
- Choice of arm inductance (L)

MMC Basics



Apply KVL to arm circuits

$$\frac{v_d}{2} = Ri_u + L\frac{di_u}{dt} + v_u + v_a$$

$$\frac{v_d}{2} = Ri_l + L\frac{di_l}{dt} + v_l - v_a$$

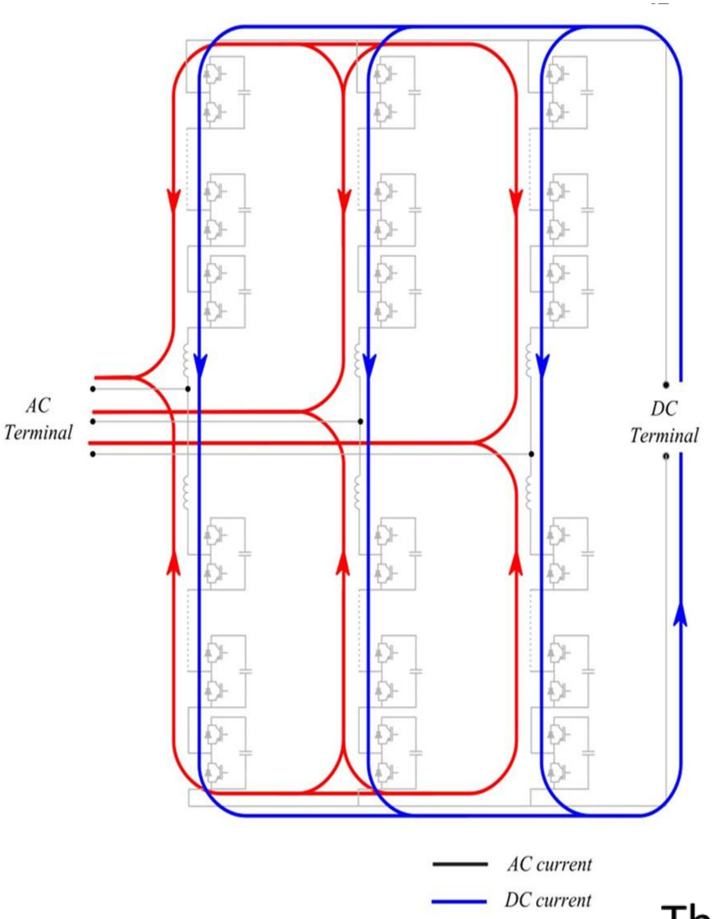
From Figure, it is evident that:

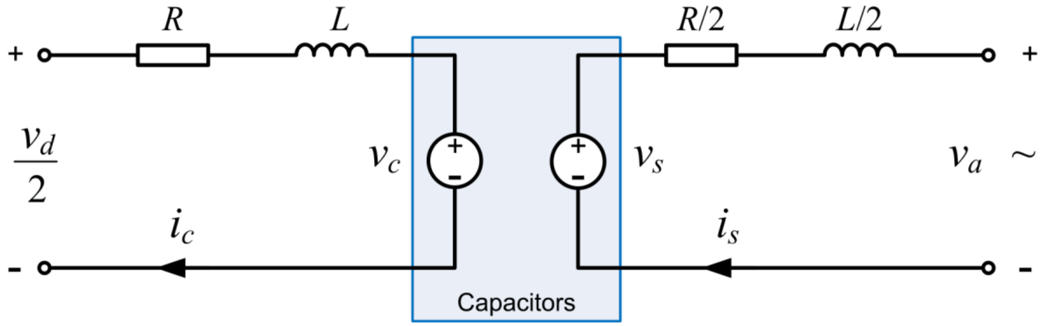
$$i_s = i_u - i_l$$

We define the circulating current i_c as:

$$i_c = \frac{i_u + i_l}{2}$$

MMC Equivalent Circuits





$$\frac{L}{2}\frac{di_s}{dt} = \underbrace{\frac{v_l - v_u}{2}}_{v_s} - v_a - \frac{R}{2}i_s$$

$$L\frac{di_c}{dt} = \frac{v_d}{2} - \underbrace{\frac{v_u + v_l}{2}}_{v_c} - Ri_c$$

The output voltage $\boldsymbol{v_s}$ drives the output current $\boldsymbol{i_s}$.
The internal voltage $\boldsymbol{v_c}$ drives the circulating current $\boldsymbol{i_c}$.

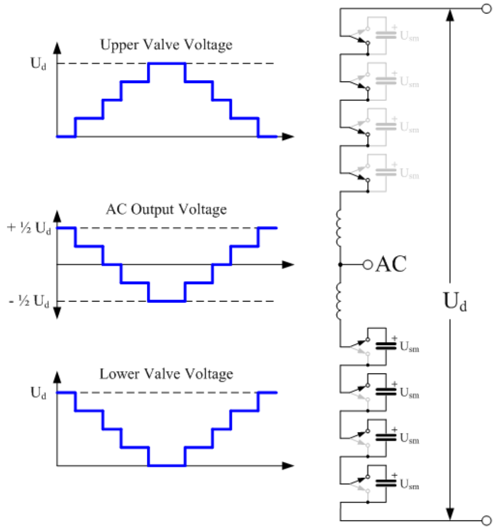
Insertion Indices

What is insertion index?
Per arm the insertion indices can be calculated as:

$$n_{u,l} = \frac{1}{N}\sum_{i=1}^{N} n_{u,l}^{i}$$

This results in the continuous model:

$$v_{u,l} = n_{u,l} v_{cu,l}^{\Sigma}$$



*MMC animation – wikipedia.

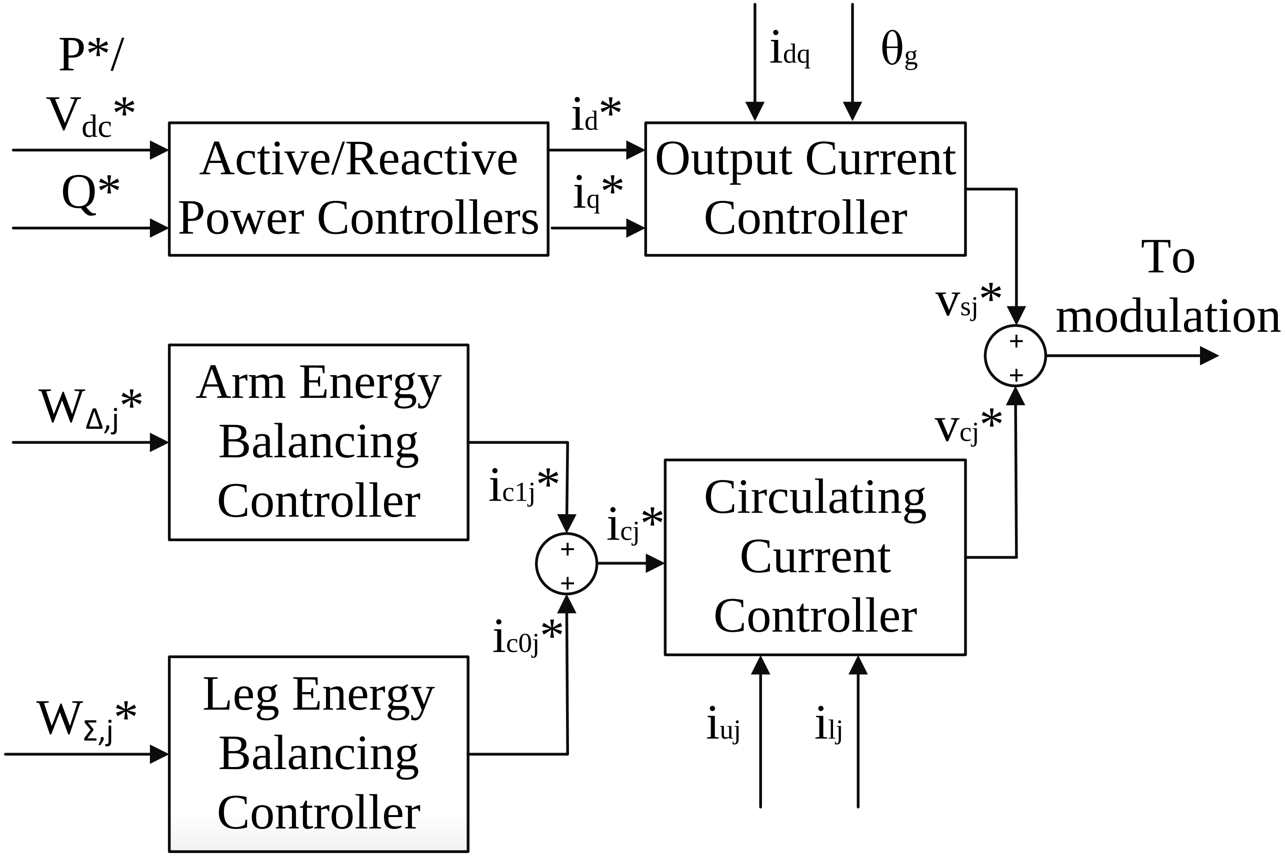
So when substituted in the MMC model it yields:

$$L\frac{di_c}{dt} = \frac{v_d}{2} - \frac{n_u v_{cu}^{\Sigma} + n_l v_{cl}^{\Sigma}}{2} - Ri_c \qquad \frac{L}{2}\frac{di_s}{dt} = \frac{n_l v_{cl}^{\Sigma} - n_u v_{cu}^{\Sigma}}{2} - v_a - \frac{R}{2} i_s$$

$$\Rightarrow \boxed{n_u = \frac{v_c^* - v_s^*}{v_{cu}^{\Sigma}} \qquad n_l = \frac{v_c^* + v_s^*}{v_{cl}^{\Sigma}}}$$

The currents can be controlled via the insertion indices.
The controller has two degrees of freedom.

Control Structure



Challenges in HVDC Grids

HVDC grid realization key aspects

- System Integration
- Dynamic Behavior
- Fault Response

System Integration

MMC Scalability

- **Massive series connection** of semiconductors is **not required** (as in 2-level VSC) to handle the dc voltage in HV applications;
- **Easily scalable** through plug-in modules (capability of integrating different number of racks in the system);
- **Redundancy;**
- **Optimization** is needed to decide number of SMs vs. levels of harmonic distortion and converter losses.

TU Delft

System Integration

MMC-HVDC Station Components

- **Transformer**
  - **Normal operation:** parallel connection of two transformers at 70-75% of nominal rating, naturally cooled;
  - **Emergency operation:** one transformer, overloaded with possibly forced cooling, which equates to 100% of nominal scheme rating.
- **Phase reactors and DC pole reactors**
  - **Air core phase reactors**
    - Suppress circulating current;
    - Limit rate of rise of fault currents;
    - Located in a separate room next to converter valve hall.

System Integration

MMC-HVDC Station Components

- **DC pole reactors**
  - In series with converter pole;
  - Smooth dc ripple and harmonics;
  - Limit peak and rate of rise of dc fault currents.

- **Converter valve hall**
  - Two valve halls usually, each containing three arms;
  - Surge arresters on each arm;
  - Each arm has SM stacks;
  - Each SM has IGBTs, dc capacitors, drivers and protection;
  - Forced water-cooling.
- **Additionally:** Control, protection and communication equipment, ac and dc switchyards, auxiliary systems.

System Integration

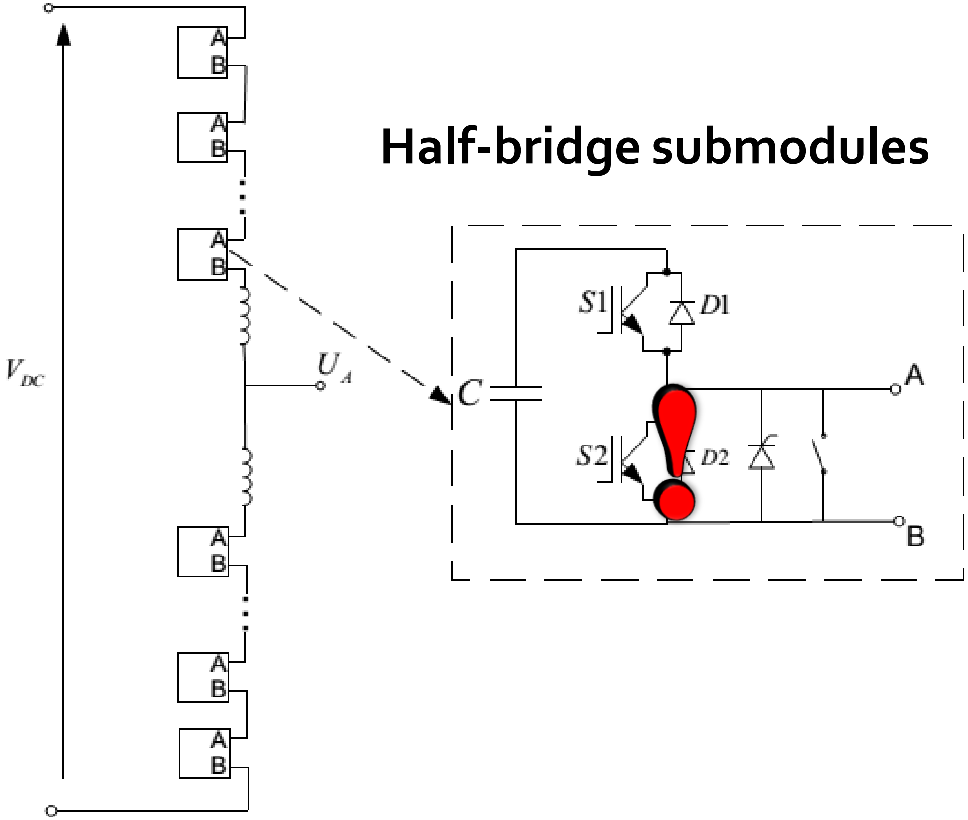

SIEMENS HVDC PLUS **ABB HVDC Light** **GE HVDC MaxSineTM**

Towards MTdc grids main **challenges** arise:

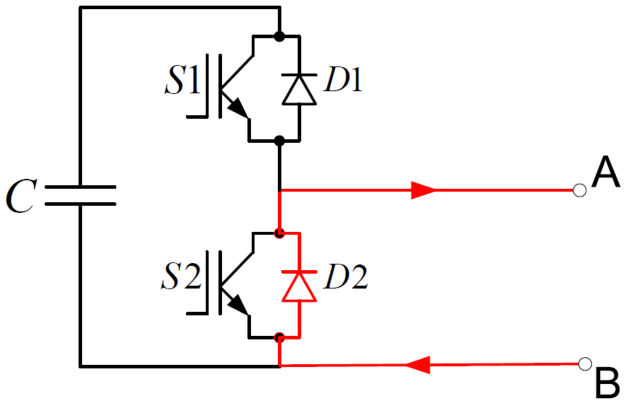
- Many **different voltage levels** currently used;
- **Lack of** HVDC equipment **standardization**;
- **Different design approaches** by major manufacturers;
- **Different protection principles**;
- **Different control** structures with limitation in coordination;
- **Communication issues**.

Protection Issues

Half-bridge MMC-HVDC connections

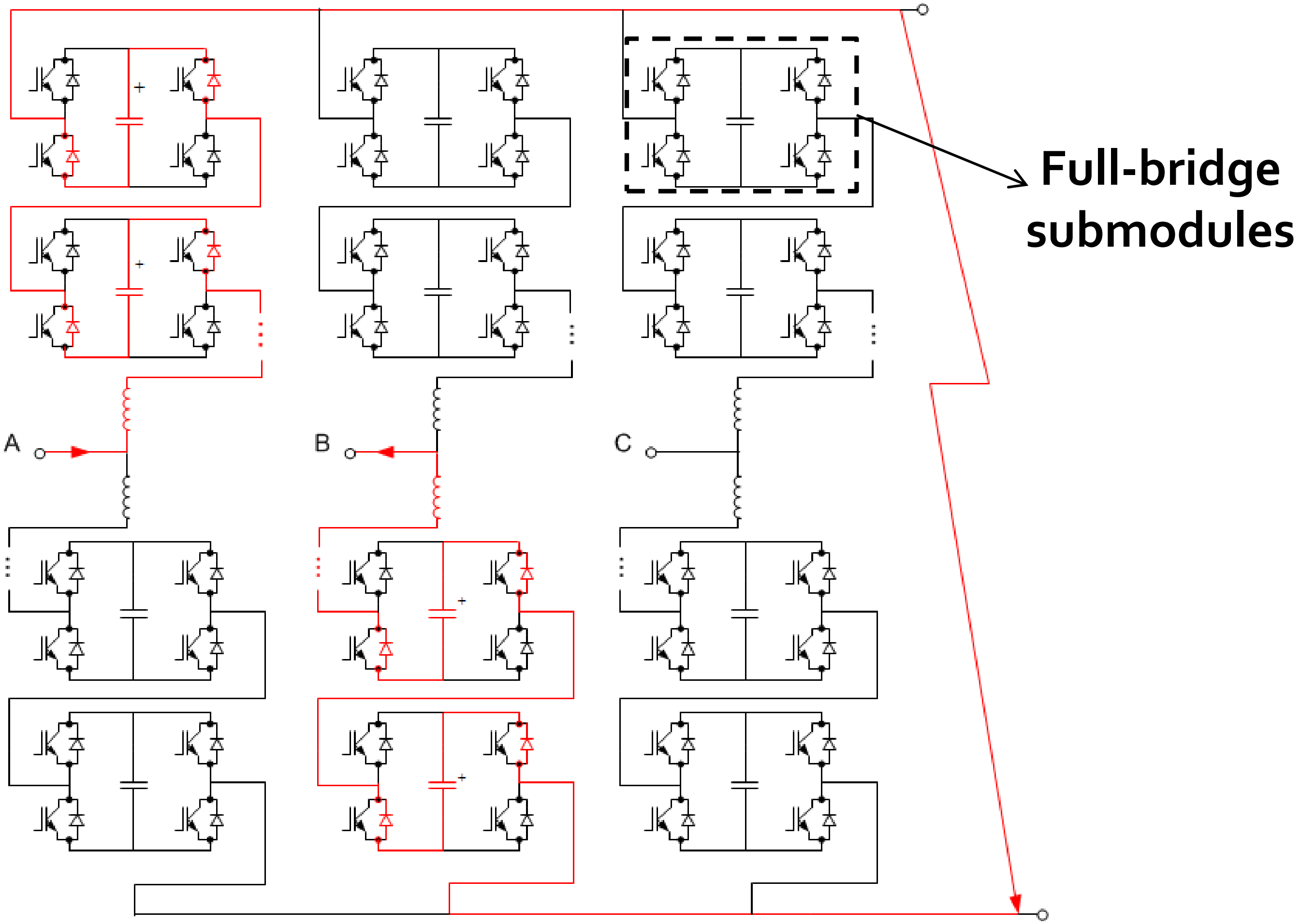


Half-bridge submodules



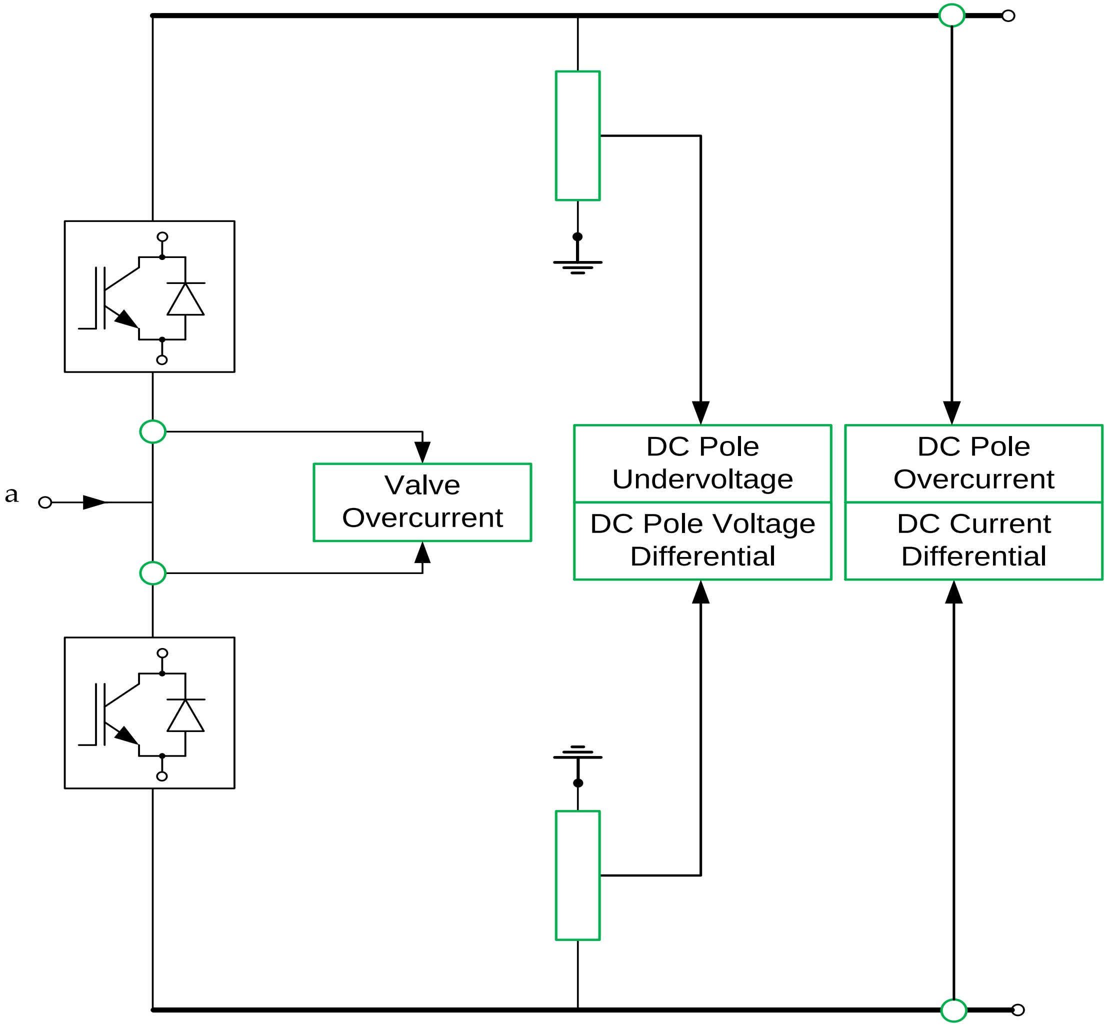
Fault state

Protection Issues



Full-bridge submodules

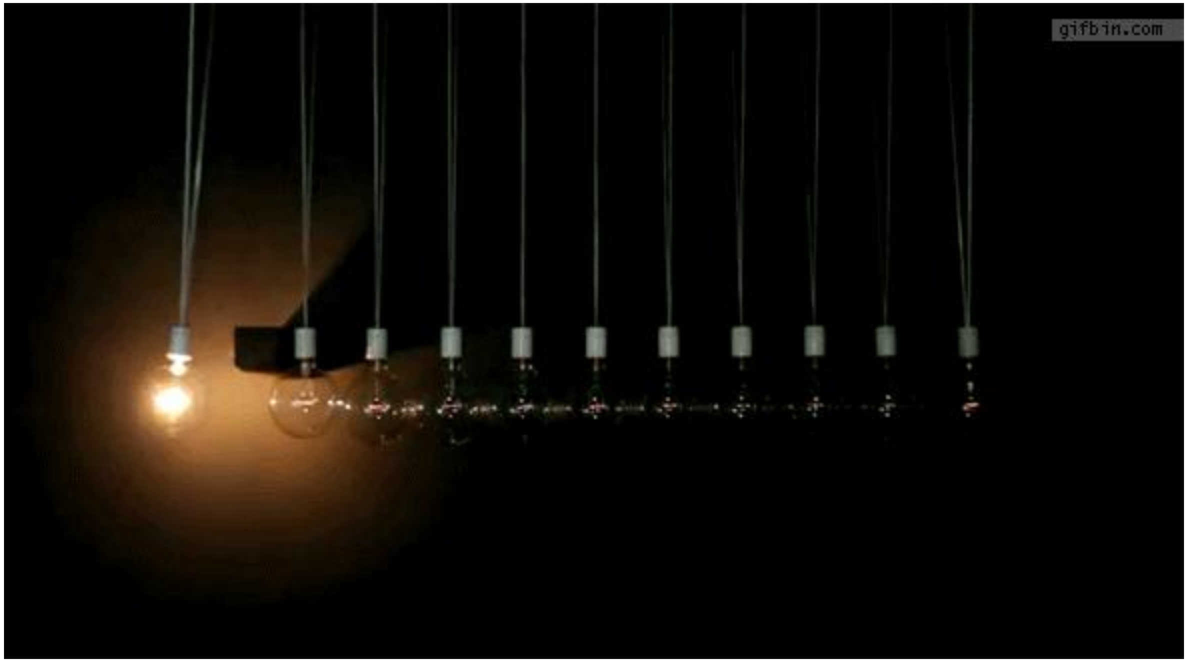
DC Fault Detection



Summary

- Design, control and integration of MMC in a grid is a multifaceted problem.
- System integration studies reveal the advantages of MMC technology.
- MMC provides additional operational flexibility in contingencies both on the ac and the dc side.

Questions?



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