EMTP-RV

The reference for power systems transients

EMTP-RV Models and Simulations of Alternate Arm Converters

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EMTP User Conference
30/08/2022

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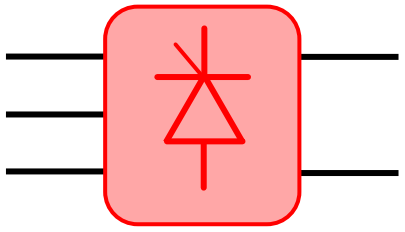
Context of this work

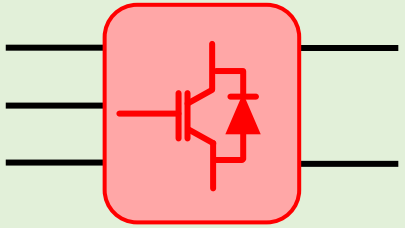
The current power system is dominated by the **HVAC** technology

HVDC transmission systems gain attention all over the world:

- Strengthen countries interconnexion
- Connection of remote sources (e.g. WF)



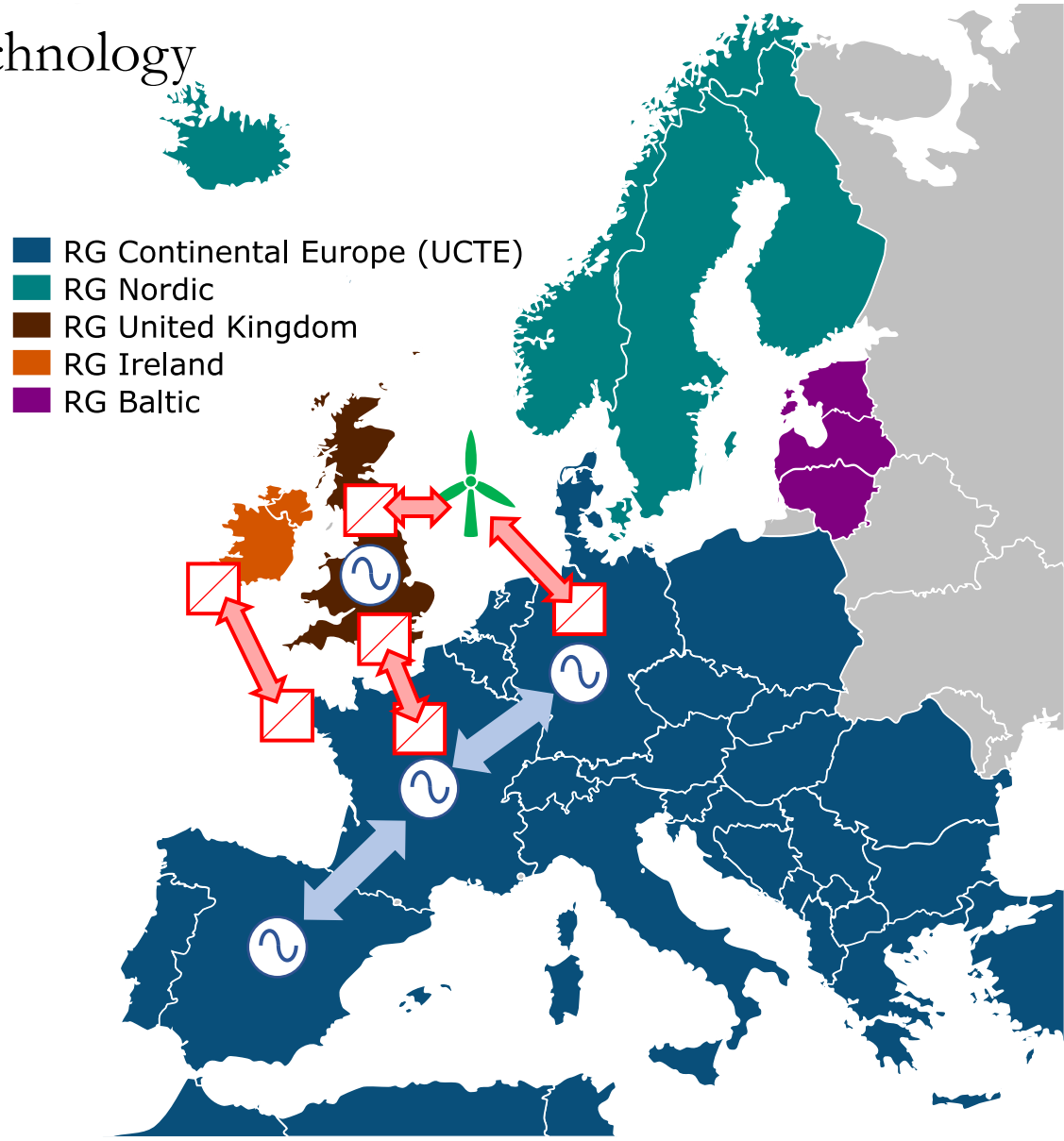
LCC



VSC

Trend in Europe:

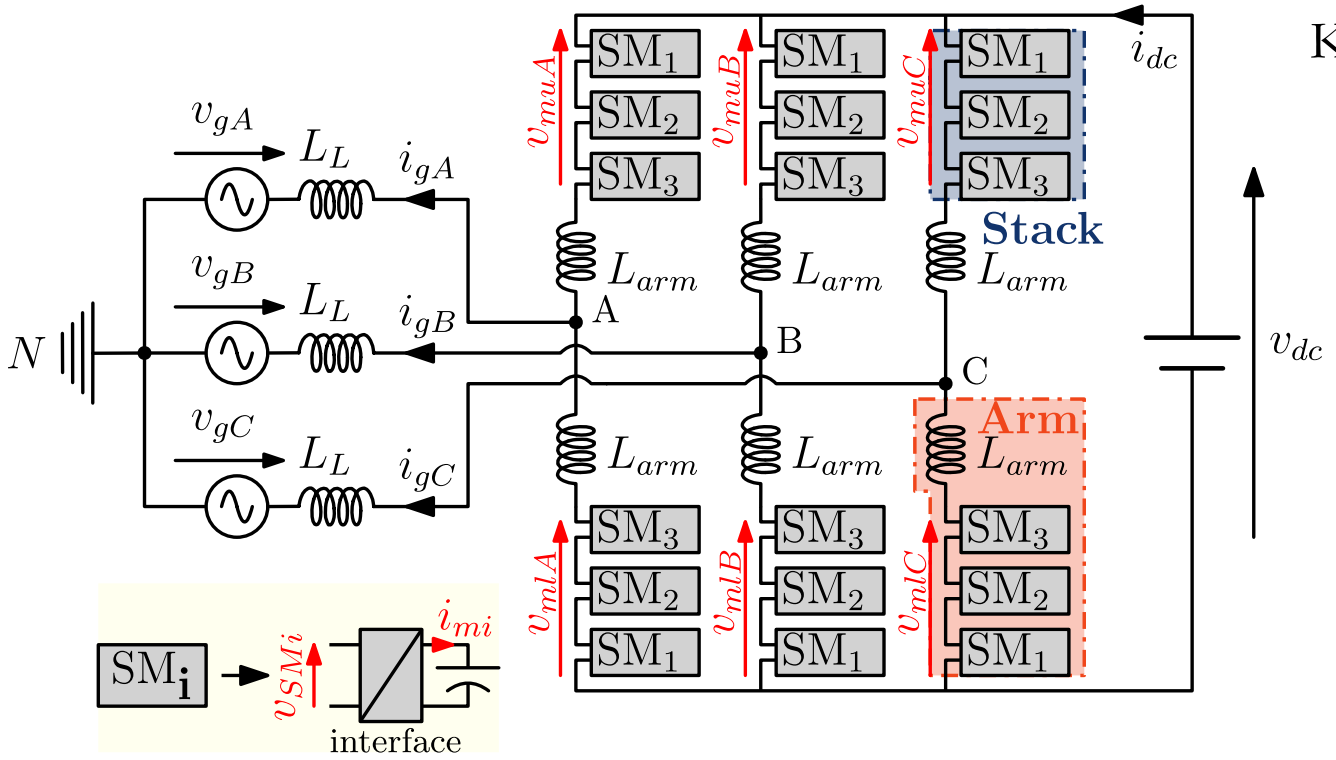
Multilevel VSC



https://fr.wikipedia.org/wiki/Electricité_en_Euro

Context of this work

The Modular Multilevel Converter (MMC) → A technological breakthrough early in the 2000's for HVDC stations



Key of this topology : **Stacks of Sub-Modules (SM)**

- Modular design
- Low harmonic content
- High power capability
- High efficiency

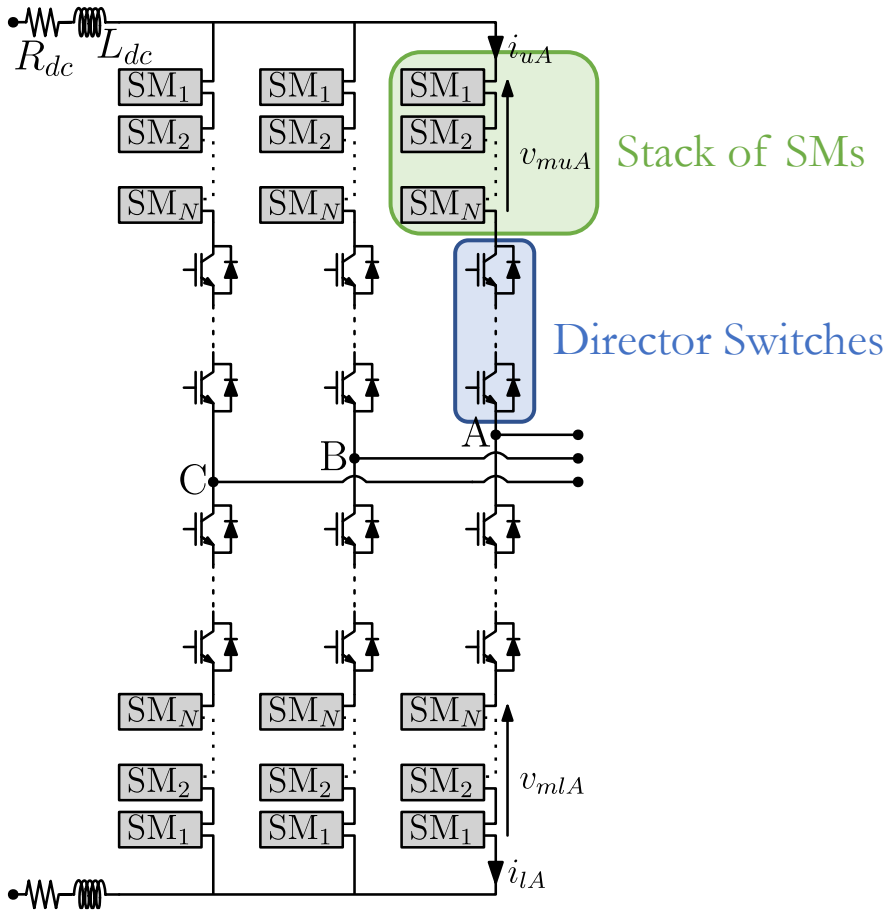
- High number of SMs/stack
- Large internal energy storage

The MMC is the leading solution for HVDC project of ~[0.5 ; 2.5] GW

Can the MMC be challenged ?

Context of this work

One possible answer: **Hybrid modular topologies**



The Alternate Arm Converter (AAC)

Claims:

- **A fewer SMs compared to MMC**
- **Station footprint reduction (compared to MMC)**
- **DC-Fault blocking capability**
- **Low level of losses**

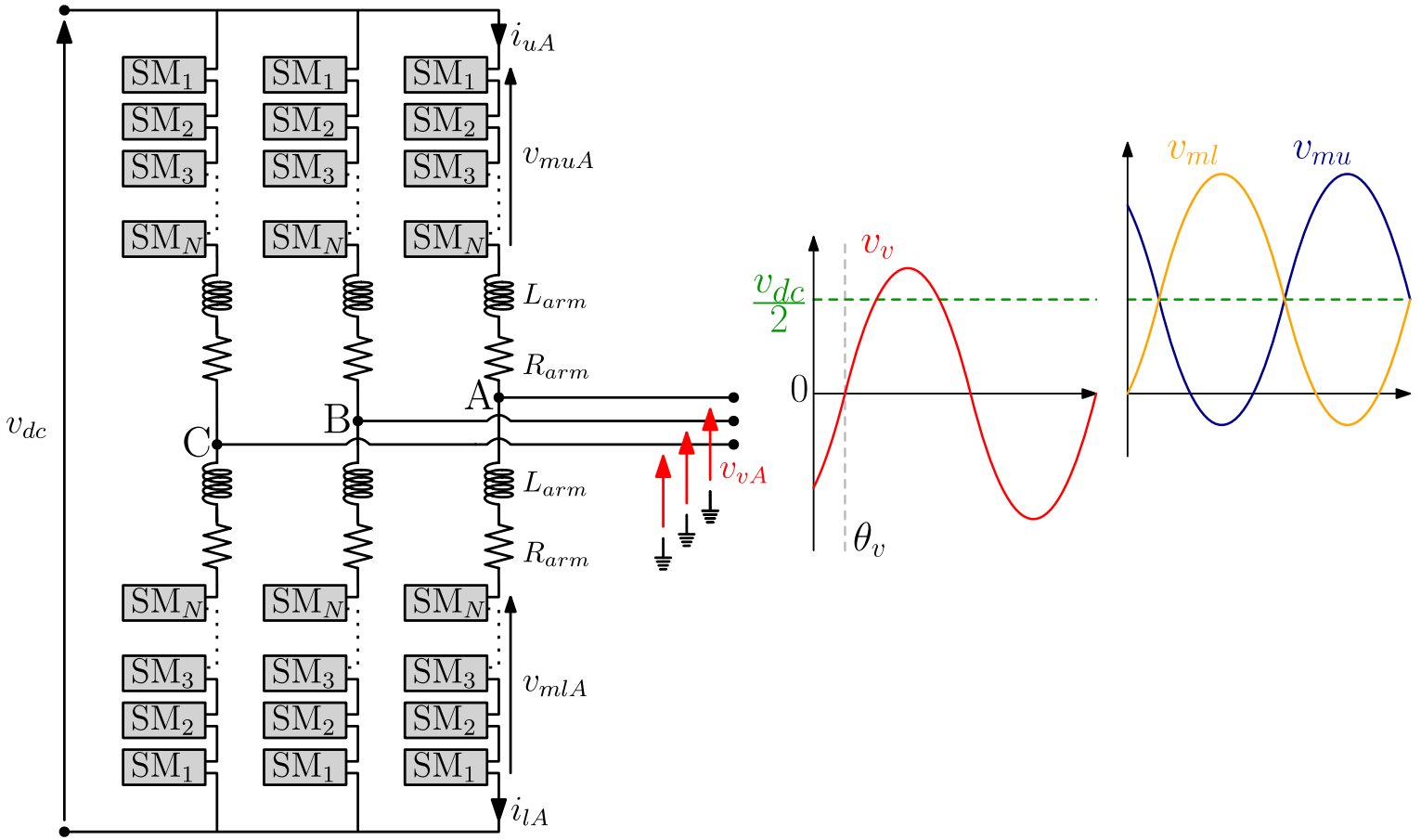
Good candidate for HVDC offshore substations

[1] M. M. C. Merlin *et al.*, "The extended overlap alternate arm converter: A voltage-source converter with DC fault ride-through capability and a compact design," *IEEE Trans. Power Electron.*, vol. 33, no. 5, pp. 3898–3910, 2018.

Outline

I. Introduction to the AAC topology
II. Models and Controllers
III. Results in stand-alone
IV. Performance in the power system

Recall on MMC voltage modulation principle



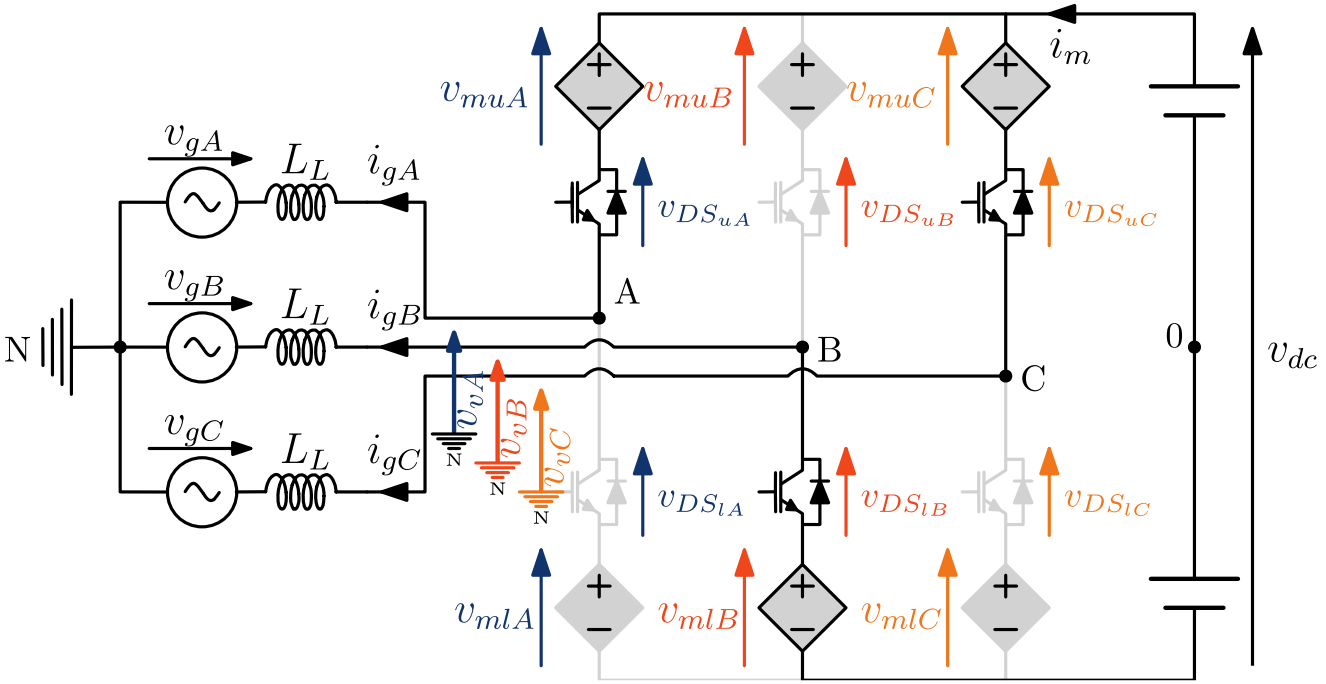
Each of the 6 arms **always** participates to :

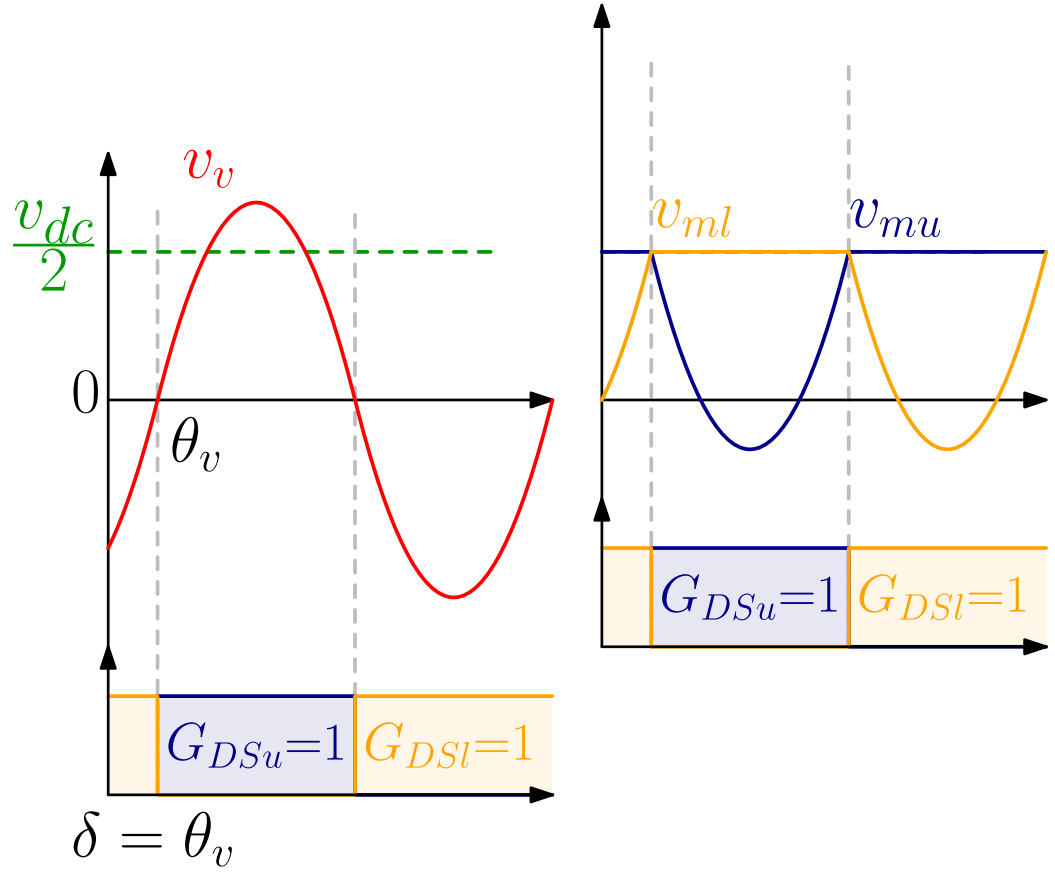
- AC voltages construction
- Maintain DC voltage constant
- Keep internal energy under control

It results in:

- Smooth AC currents
- Constant DC current in any situations
- Evenly distributed energy among stacks

Modulation of AC voltages considering DSs





$$v_v = \boldsymbol{G_{DSu}} \cdot \left(\frac{v_{dc}}{2} - v_{mu}\right) + \boldsymbol{G_{DSl}} \cdot \left(-\frac{v_{dc}}{2} + v_{ml}\right)$$

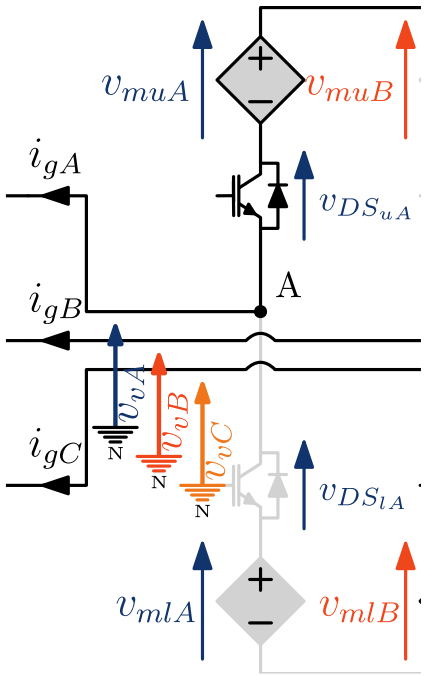
Complementary Gate Signals of DS

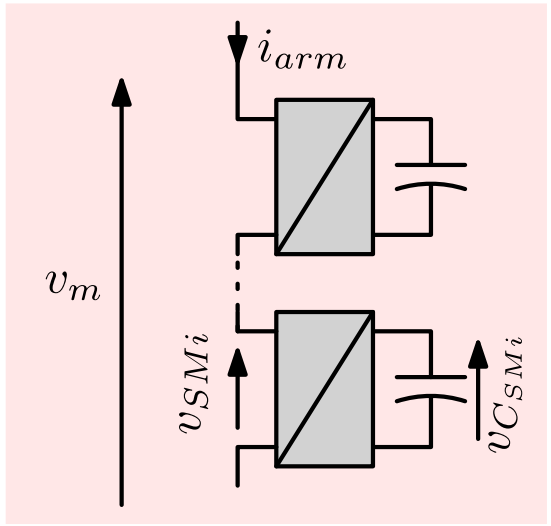
Internal voltage sources are sized for vdc/2

50% less than the HB-MMC

“Alternate Arm” operations

BUT, this is theoretical…

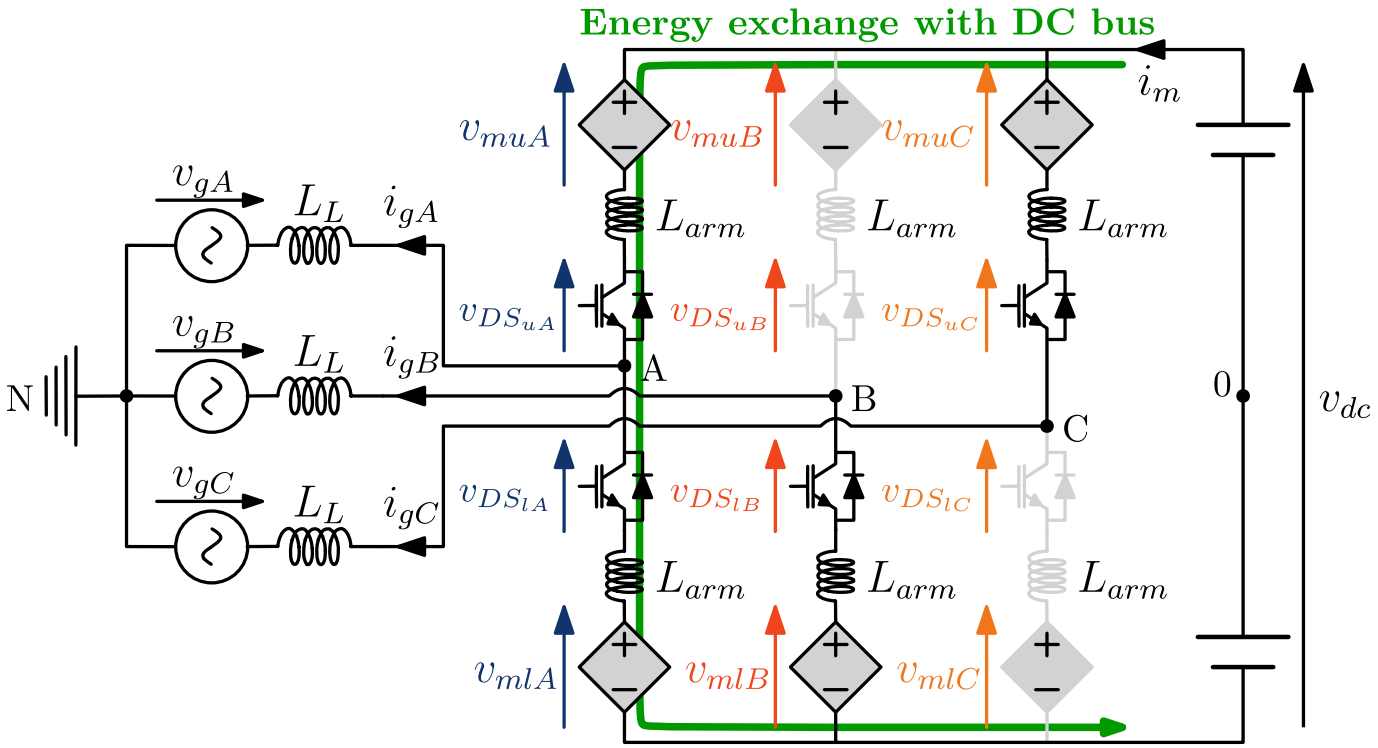




When an arm is 'on', the grid current is flowing into the capacitor, hence, the energy is diverging

A control of the energy has to be achieved.

The Overlap period

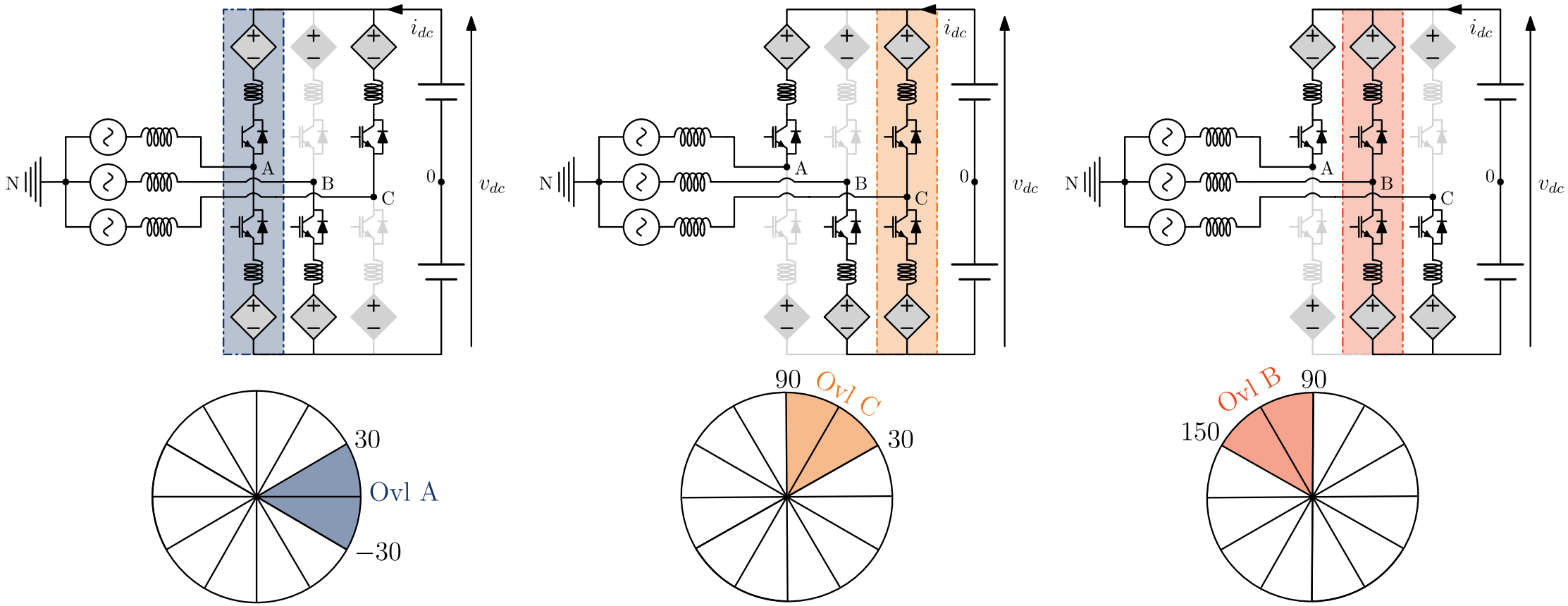


The 2 DS are switched on in the same time

The AAC is operating as a MMC ⇒ Increase of the number of submodules

The extended overlap period EO-AAC

The **overlap period fixed to 60 degrees** → **Always one leg in overlap mode**

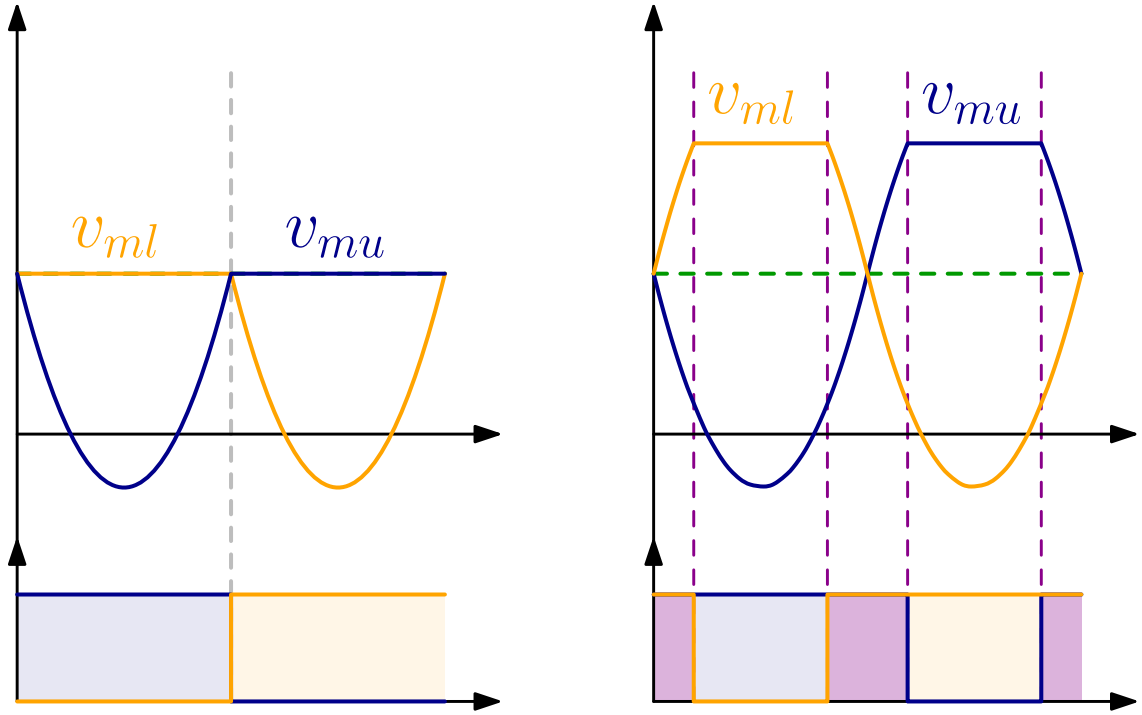


There is always on phase which is in overlapp mode

In steady state the DC current is constant, no need to add any filter

Stack of SMs sizing of the EO-AAC

Extended Overlap period → Each arm conduct for 240°

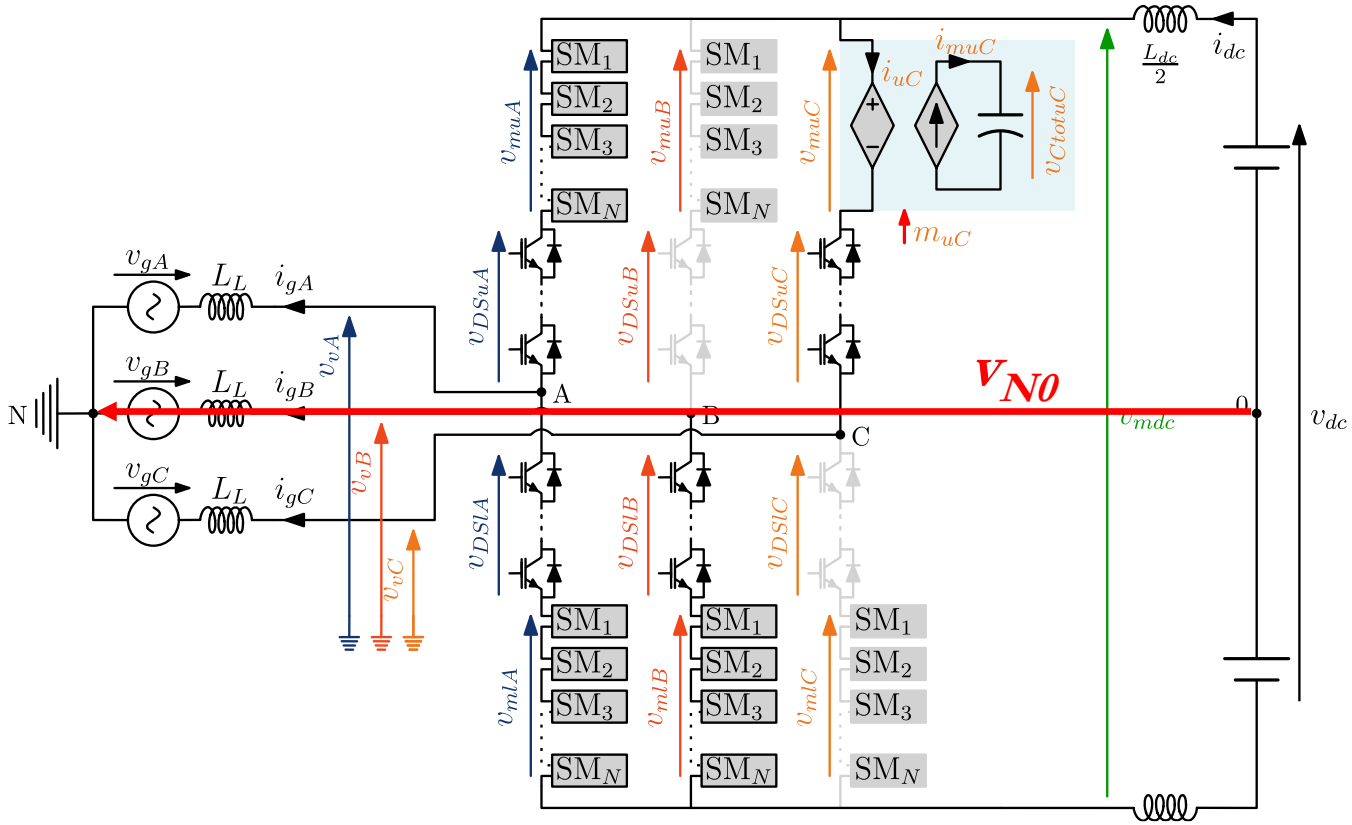


Cost of the extended-overlap period:

~+65% of SMs

$0{,}5 \rightarrow 0{,}82\times V_{dc}$

Degree of freedom to act on: the zero sequence voltage injection v_{N0} (ZSVI)



With an optimal (ZSVI) $0{,}82\,V_{dc} \rightarrow\ 0{,}65 \times V_{dc}$

But increase of the Director Swich (DS) $0.79 \times V_{dc}$

Conclusion on the sizing

	HB-MMC	EO-AAC
Stacks design	Vdc	0.64 ×Vdc
Director Switches	×	$0.79 \times V_{dc}$
Energy storage	40 kJ/MVA	13 kJ/MVA
Losses	Less than 1%	Similar

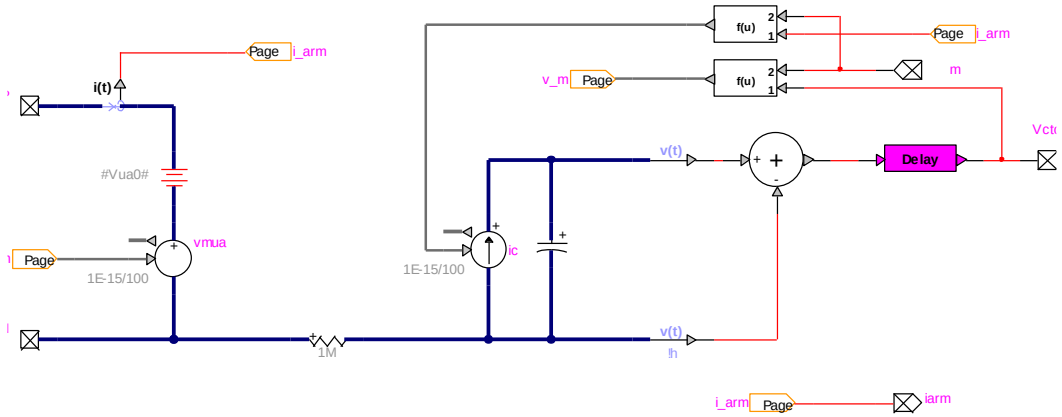
With DC Fault-blocking capability

Aim of the following : Description of models and controls implemented in EMTP-RV

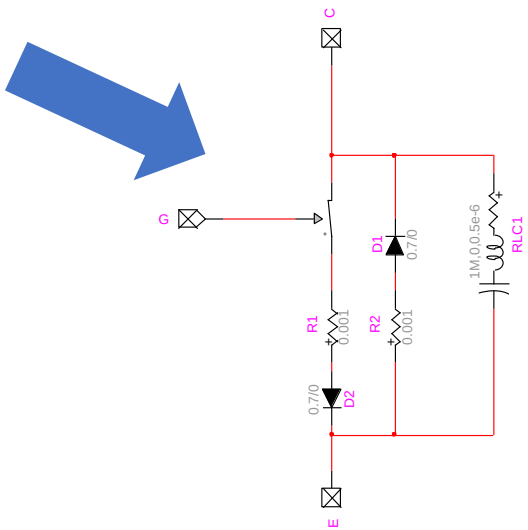
2 Types of model implemented in EMTP-RV (1/2)

To be computationally efficient and "equivalent" to detailed models:

- Each stack of SMs is replaced by one equivalent modulator[2]



- Director switches are considered as made of a single high voltage IGBT/diode
  - ➢ To avoid issues of steady-state and transient voltage imbalances of modules

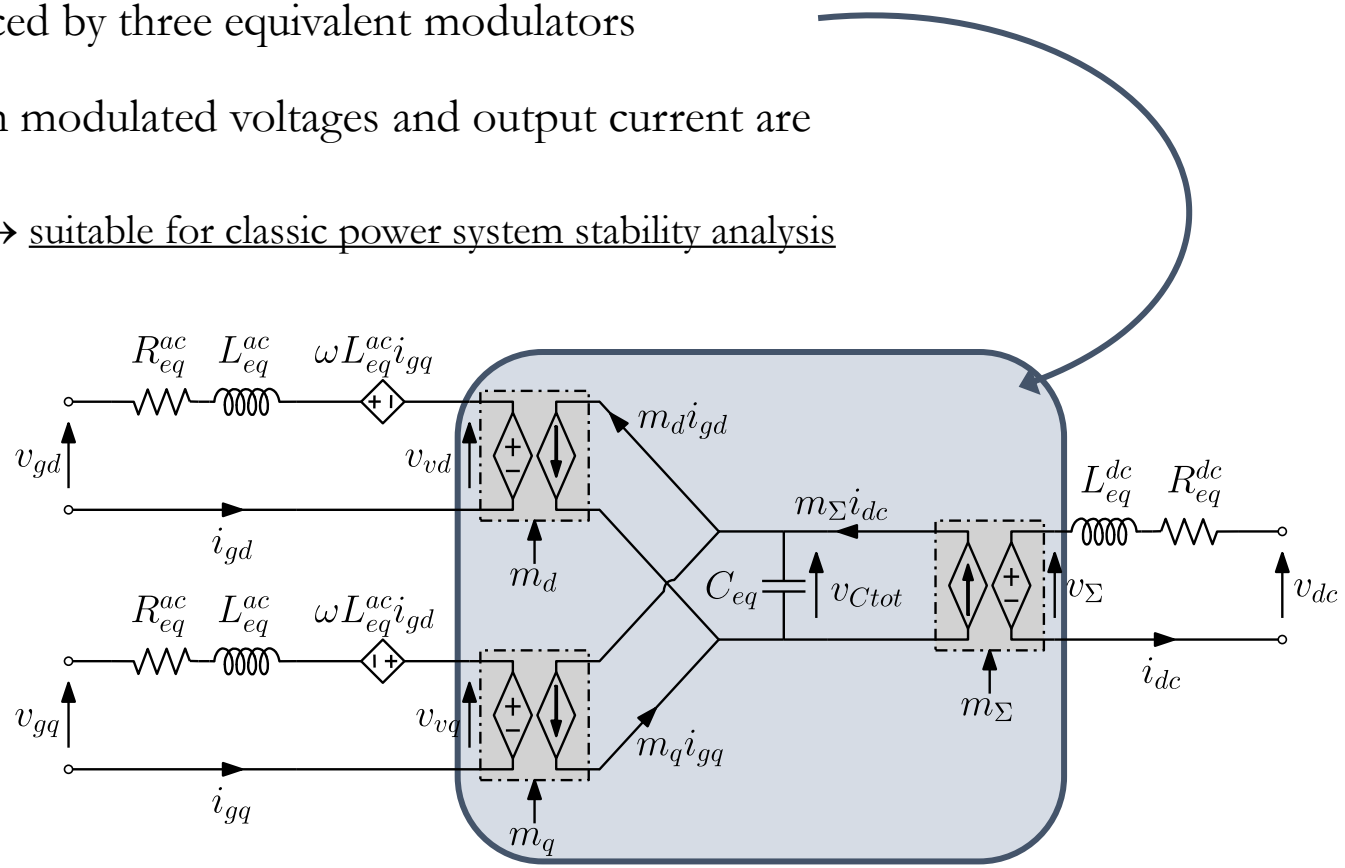


[2] H. Saad *et al.*, "Modular multilevel converter models for electromagnetic transients," *IEEE Trans. Power Deliv.*, vol. 29, no. 3, pp. 1481–1489, 2014.

2 Types of model implemented in EMTP-RV (2/2)

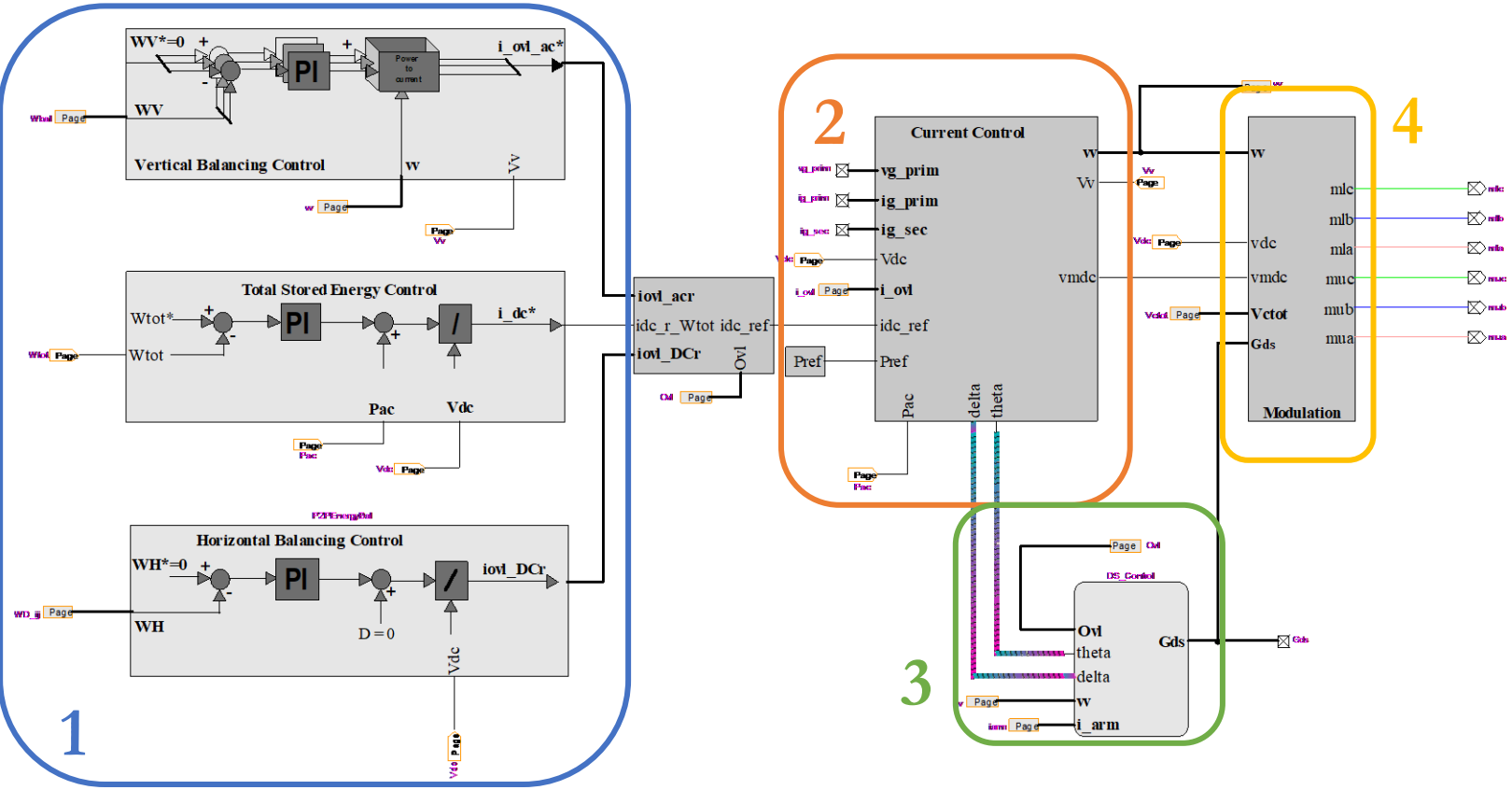
To be computationally efficient and usable for larger power system studies:

- All stacks of SMs are replaced by three equivalent modulators
- Director switches effects on modulated voltages and output current are disregarded
  - ➢ Model fully continuous → <u>suitable for classic power system stability analysis</u>



Controllers mandatory for stable operations

There is a natural energy imbalance that must be corrected. The following control has been implemented:



1 Correct the energy imbalance using:
- Total control
- Horizontal and Vertical balancing

Generates current references

2 AC and DC current controllers

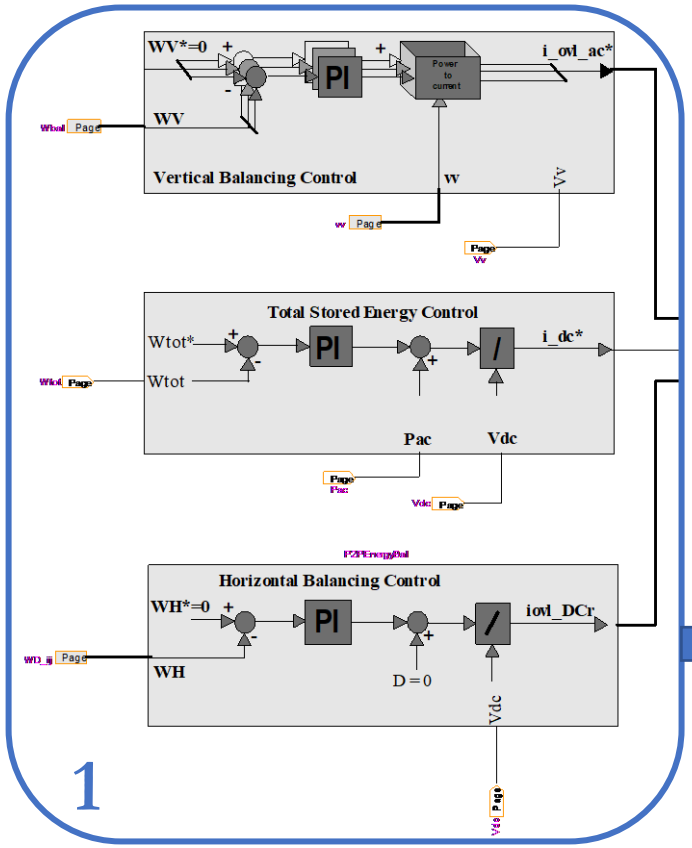
Generates AC and DC modulated voltage references

3 Determines DS gating signal values

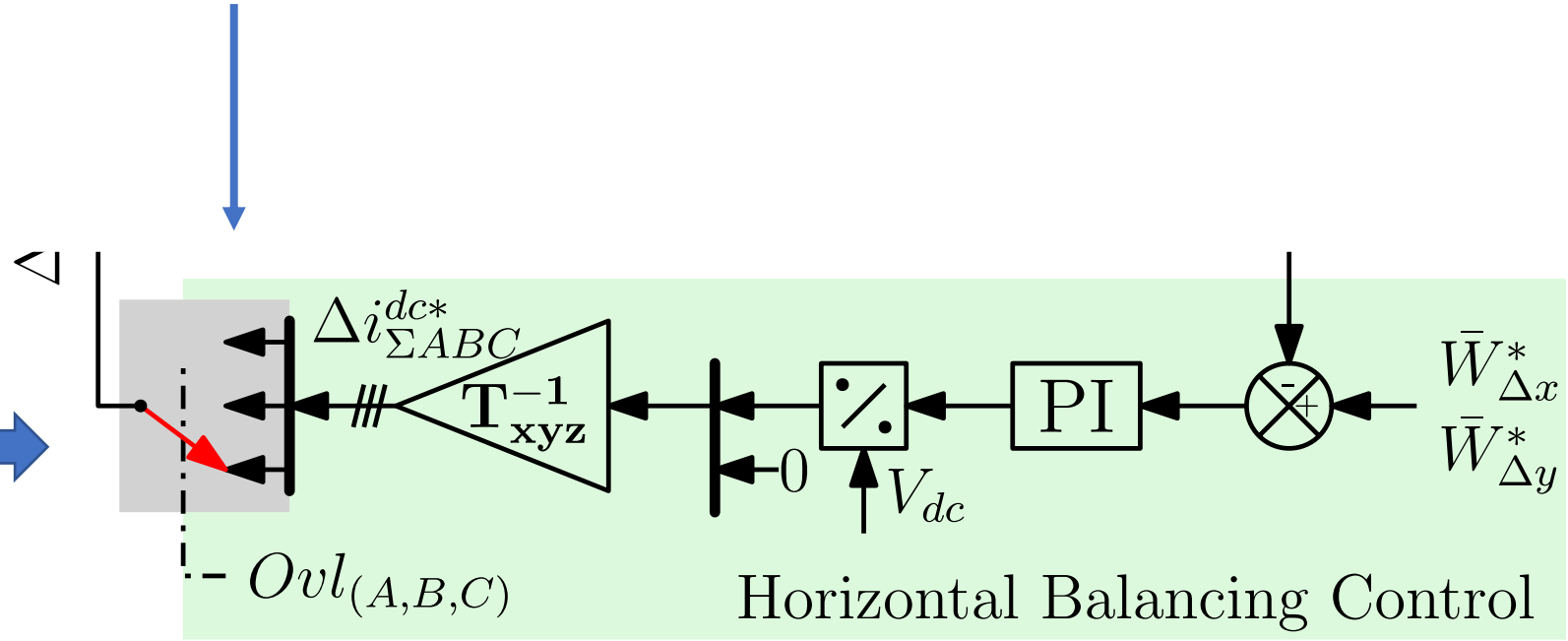
4 Generate modulation according to:
- Modulated voltage references
- DS Gating signal values
- Arm capacitor voltage levels

*For detailed models, a fifth control block would include SM capacitor voltage balancing algorithm

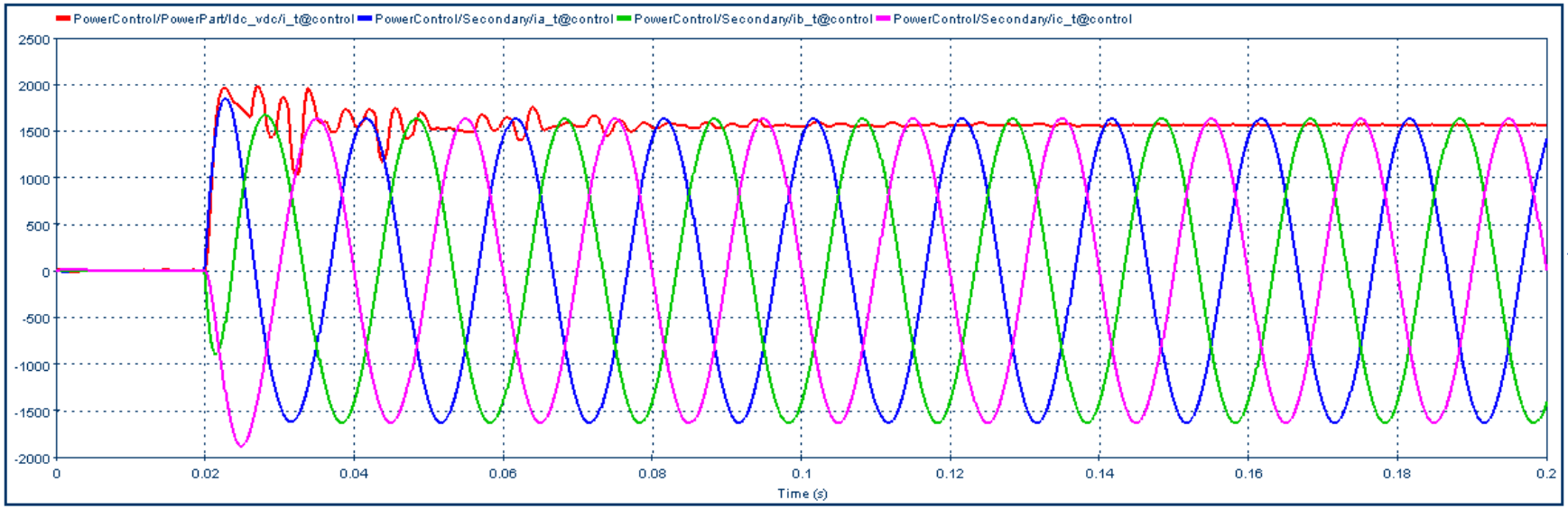
Controllers mandatory for stable operations



Need to switch the control depending on the phase which is in overlap

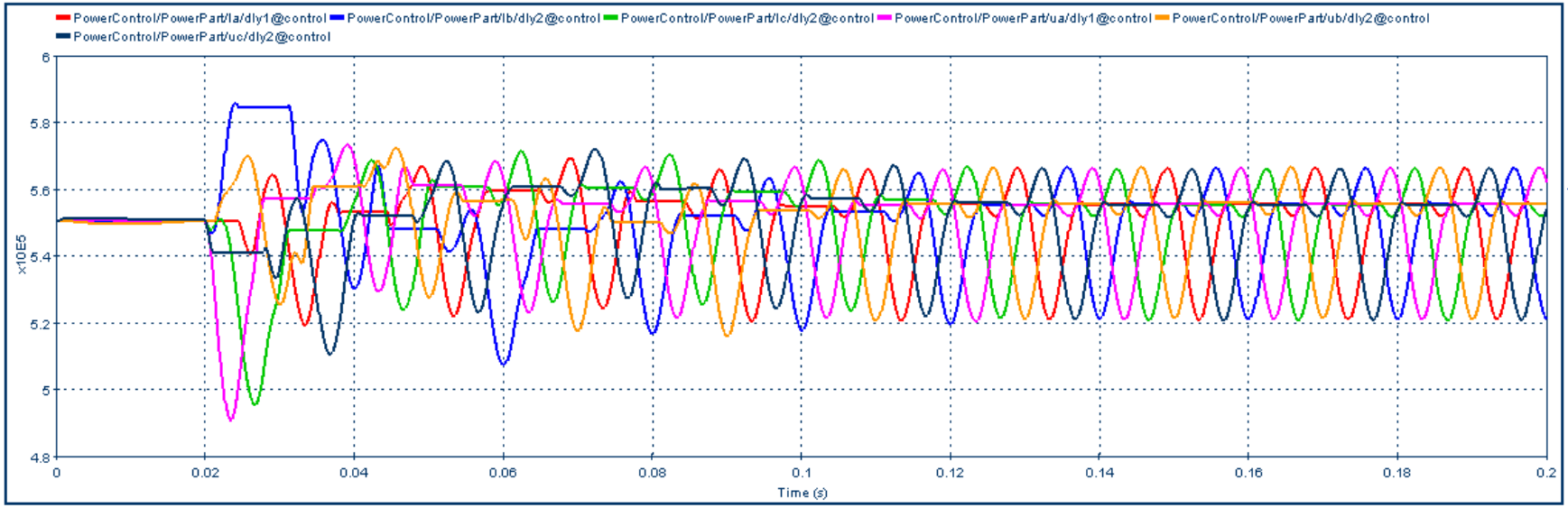


Converter behaviour when connected to perfect sources



AC and DC output currents

- Transient harmonics due to energy balancing controllers



Internal capacitor voltages

- Balanced in steady-state

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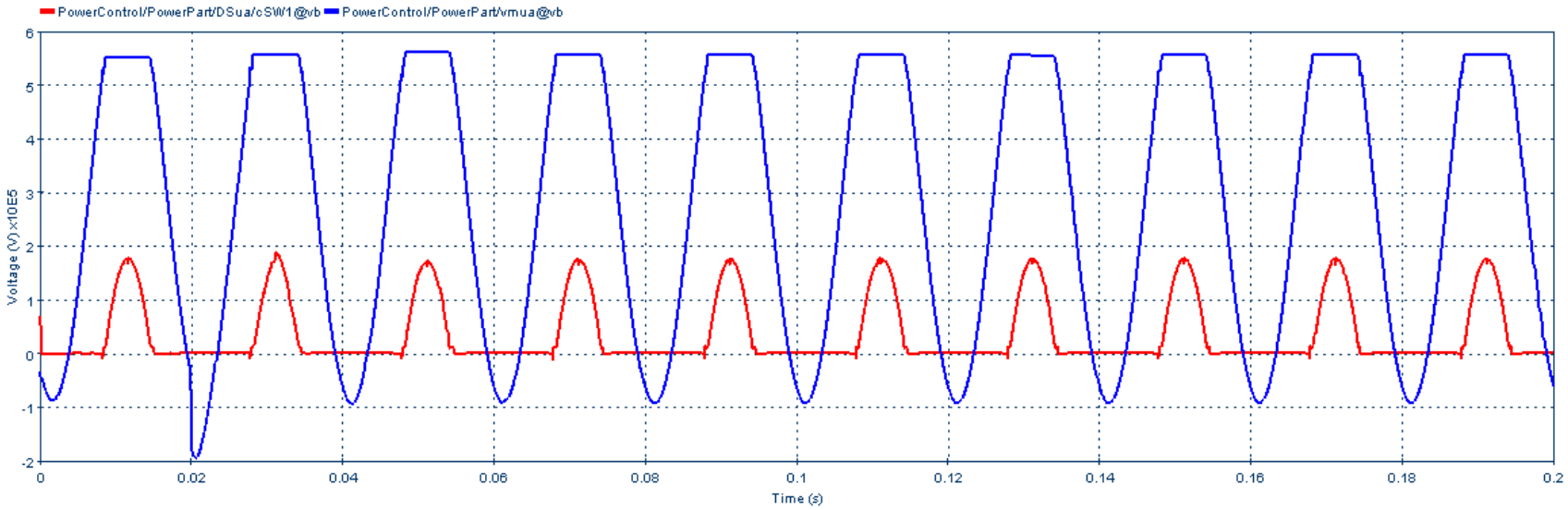
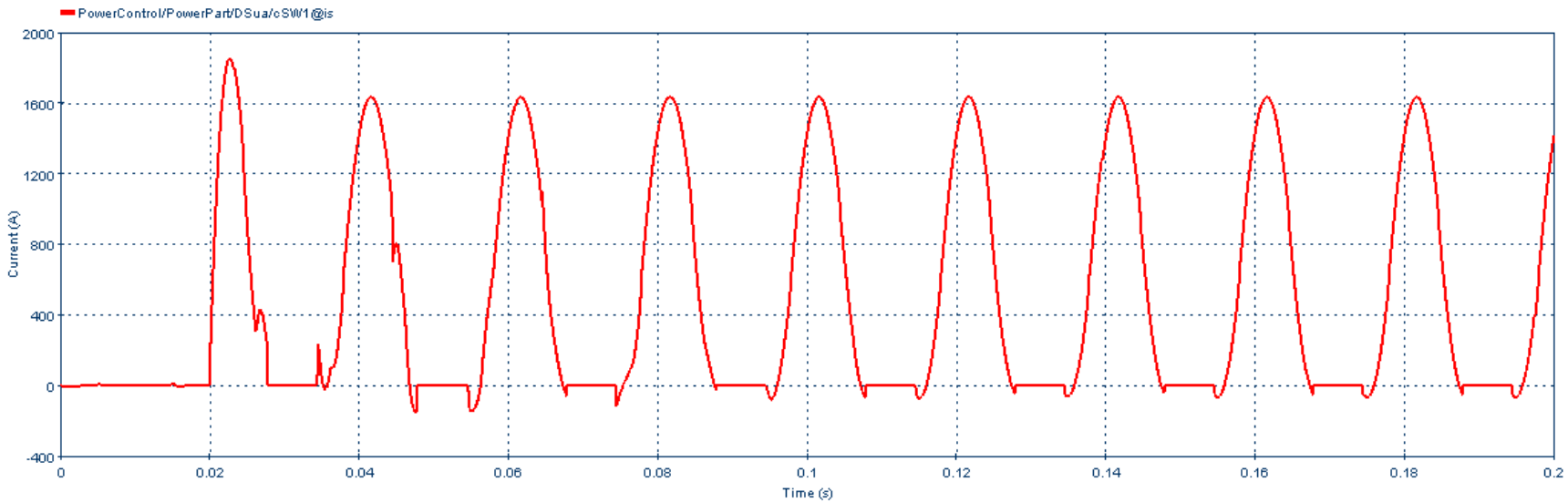
Converter behaviour when connected to perfect sources



Voltage generated by SMs

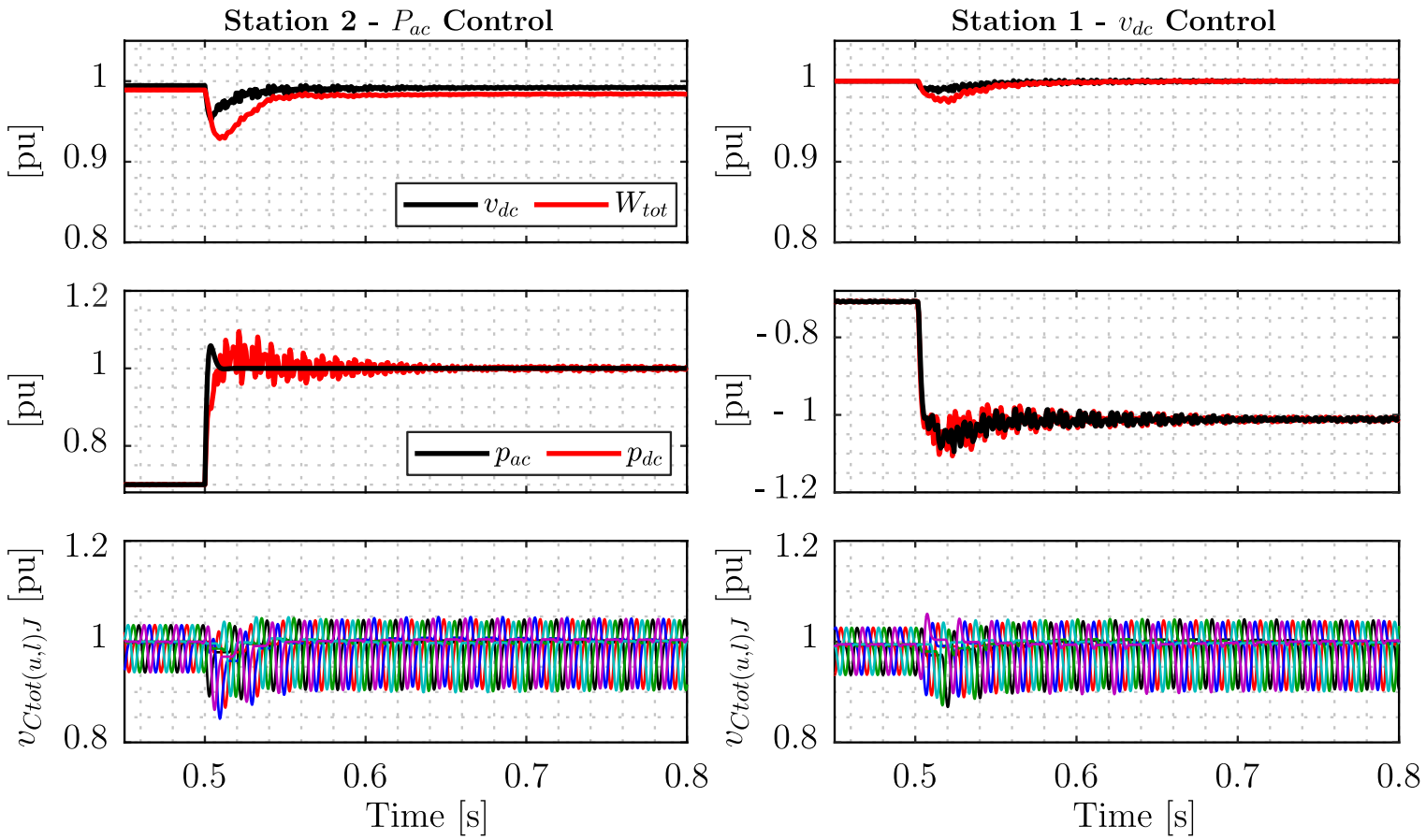
Voltage across a DC



Arm current

Behaviour when connected to DC cables

Point to point HVDC link – 300 km of HVDC cables using wideband cable model

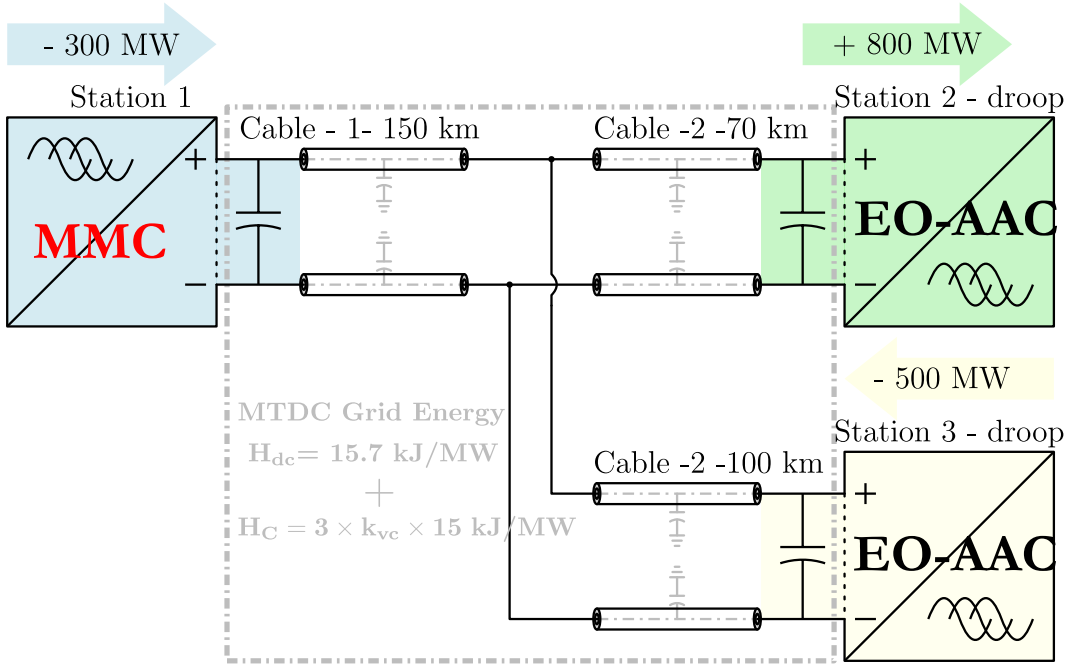


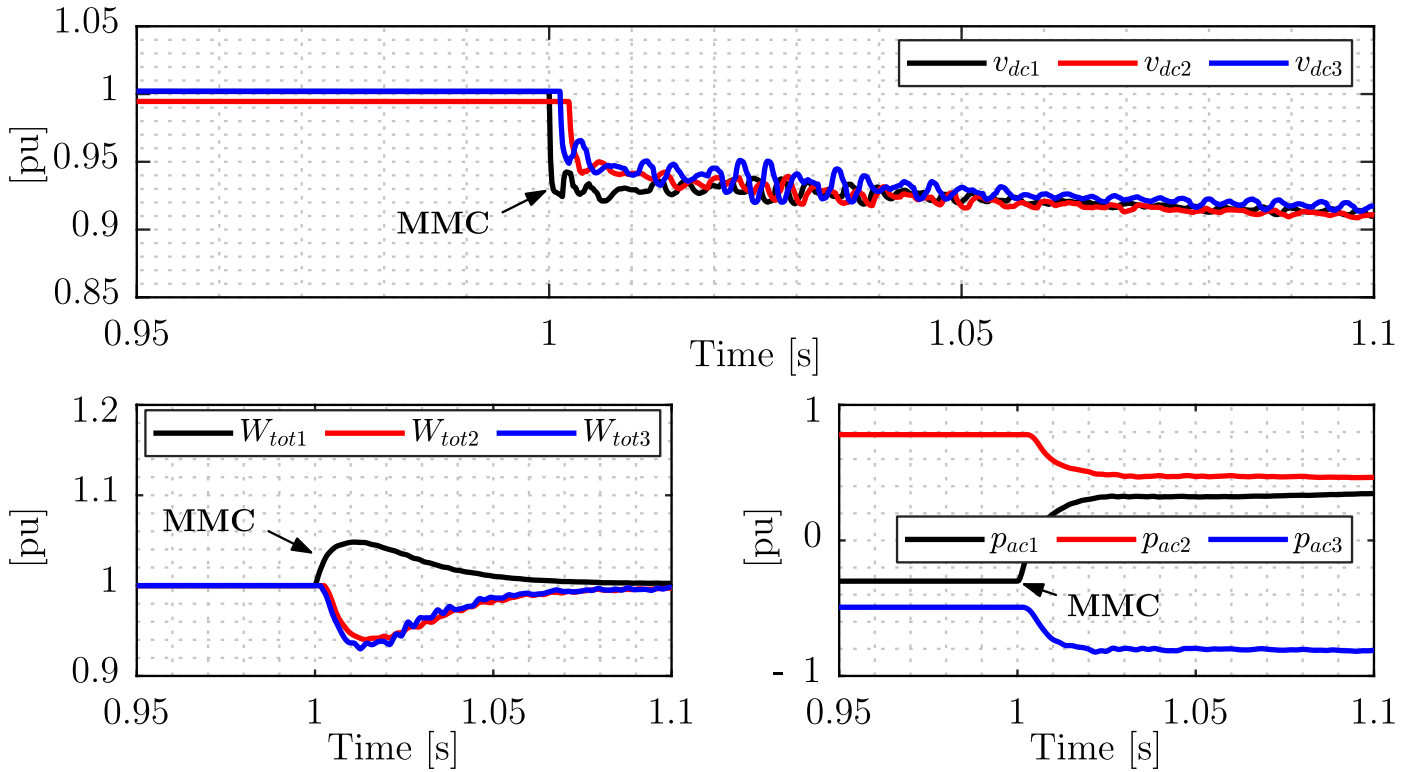
Checked:

- Overall system stability over large disturbance
- Mitigate the transient harmonics by appropriate DC voltage control & energy management
- Interoperation with HVDC stations like MMC

Behaviour in MTDC system

Three terminals MTDC system





General Conclusion

A global overview on:

- Extended Overlap-Alternate Arm Converter sizing modelling and simulation in EMTP-RV
- Its transient behaviour

Pro

Smaller footprint

Full bridge then DC voltage ride through capabitility

Neutral

Looses

Con

More complex control

Unwanted oscillations during the transient

Behaviour in case of unbalanced AC system

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General Conclusion

Expected future works:

- More study on the behaviour in case of unbalanced application
- May be an evolution of the topology to propose