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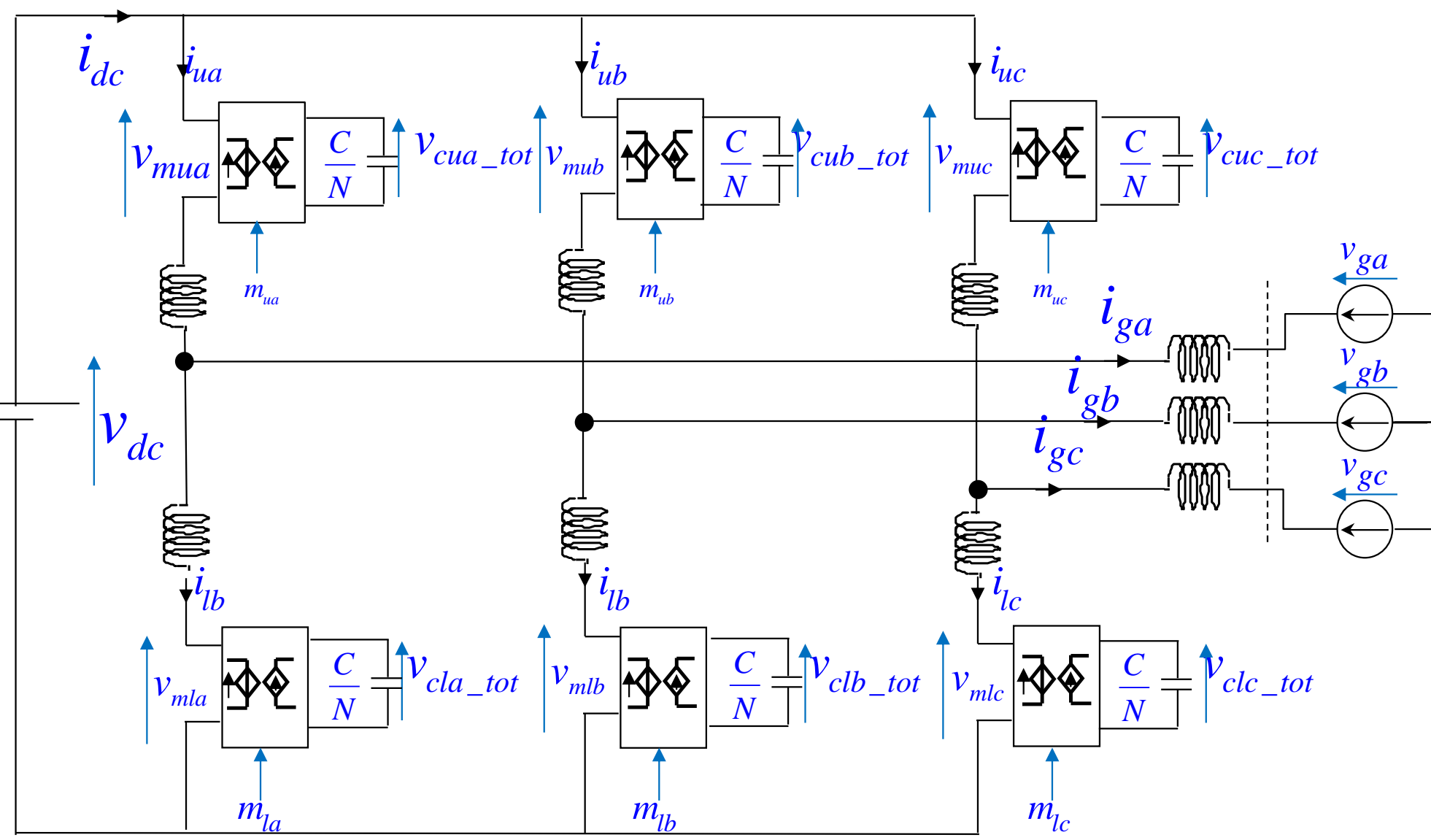
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- **Context** : control of the stored energy of the MMC (Modular Multilevel Converter)
- **Objectives** :
Study the impact of two control variants (compensation of the average or the instantaneous AC grid power) : differential and AC grid currents, capacitor voltages ripple, losses.

Simplified model of MMC

If capacitor voltage balancing is achieved:

**Modeling of the MMC converter**

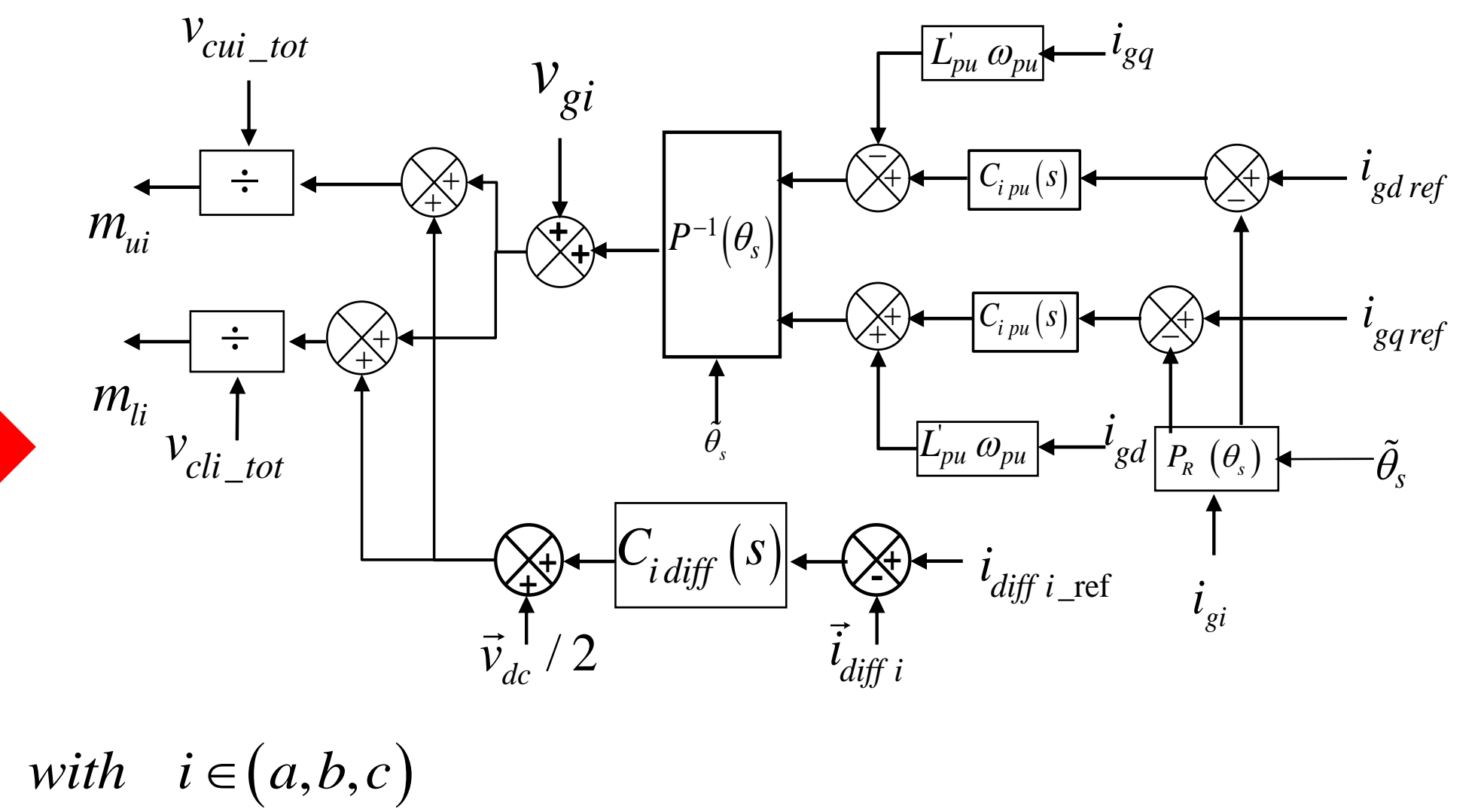
$$\begin{cases} v_{mli} = m_{li} v_{cli_tot} & ; & v_{mui} = m_{li} v_{clui_tot} \\ m_{li} i_{li} = \frac{C}{N} \frac{dv_{cli_tot}}{dt} & ; & m_{ui} i_{ui} = \frac{C}{N} \frac{dv_{clui_tot}}{dt} \end{cases} \quad \text{with } i \in (a, b, c)$$

$$i_{diff\ i} = \frac{i_{ui} + i_{li}}{2} ; v_{diff\ i} = \frac{v_{mui} + v_{mli}}{2} ; v_{vi} = \frac{v_{mli} - v_{mui}}{2}$$

$$v_{ud} - v_{gd} = (L + \frac{L_{arm}}{2}) \frac{di_{gd}}{dt} + (R + \frac{R_{arm}}{2}) i_{gd} + (L + \frac{L_{arm}}{2}) \omega i_{gq}$$

$$v_{uq} - v_{gq} = (L + \frac{L_{arm}}{2}) \frac{di_{gq}}{dt} + (R + \frac{R_{arm}}{2}) i_{gq} - (L + \frac{L_{arm}}{2}) \omega i_{gd}$$

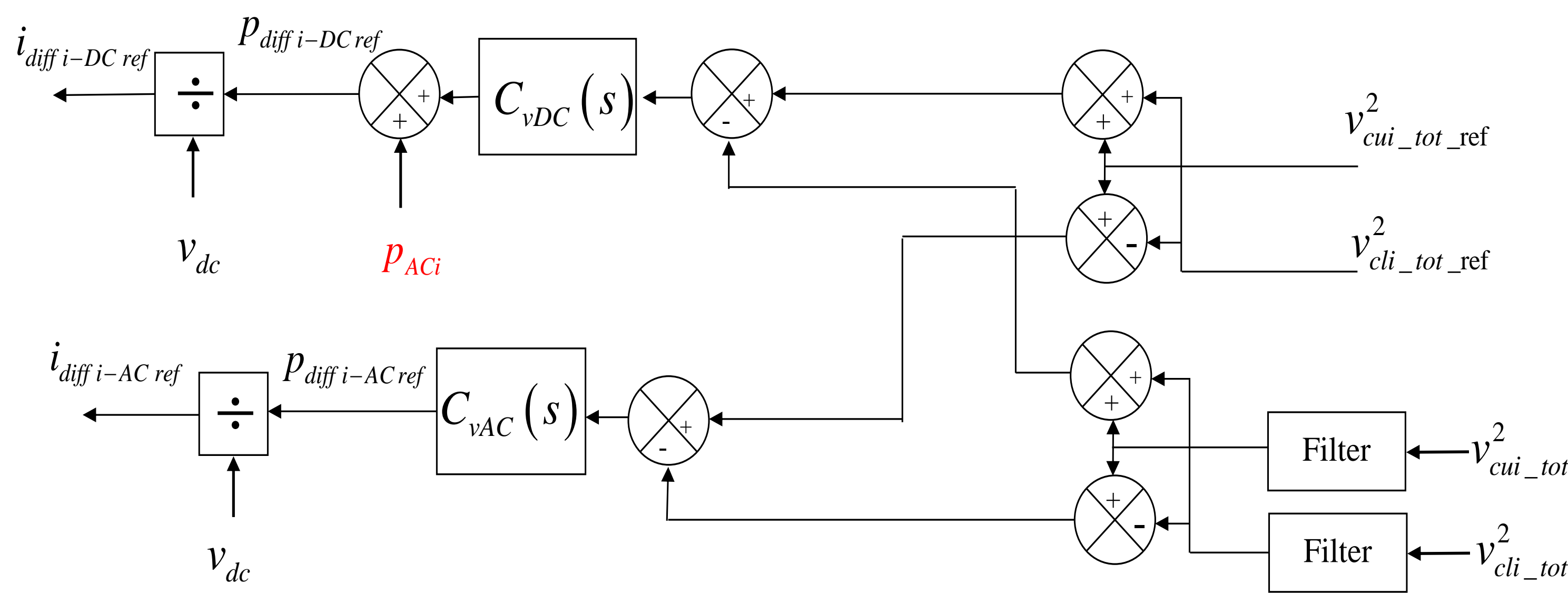
This converter has 11 independent state variables
→ Requires 11 control loops to achieve the global control

Current Control of the MMC Converterwith $i \in (a, b, c)$

Current control → 5 control loops

Stored Energy Control of the MMC Converter

$$\begin{cases} \left(\frac{d(W_{cli} + W_{cui})}{dt} \right)_T = V_{dc} i_{diff\ i-DC} - P_{AC\ i} \\ \left(\frac{d(W_{cli} - W_{cui})}{dt} \right)_T = \hat{v}_{vi} \hat{i}_{diff\ i-AC} \end{cases} \quad \text{with } i \in (a, b, c)$$



Stored Energy Control → 6 other control loops (3*sum+3*difference)

Usual assumption:

To Limit the losses, the I_{diff-i} value is limited by considering only the average power of the AC grid (P_{ac}) in the stored energy control ($P_{AC} \neq P_{DC}$)

$$p_{ACi} = \frac{P_{AC}}{3} \quad \text{with } i \in (a, b, c)$$

→ introducing the AC fluctuating power term

$$p_{ACi} = \frac{P_{AC}}{3} + V_{gi} I_{gi} \cos(2\omega t + \varphi) \quad \text{with } i \in (a, b, c)$$

-Reduce the ripples in the v_{c_tot} since $p_{AC} = P_{DC}$

The choice of introducing or not the fluctuating part of the AC power modifies the control →

- different quantity of activated sub-modules
- current passes through a different number of IGBT and diodes.

it may have sense to use a control inducing a slightly larger current if this current passes through more diodes.

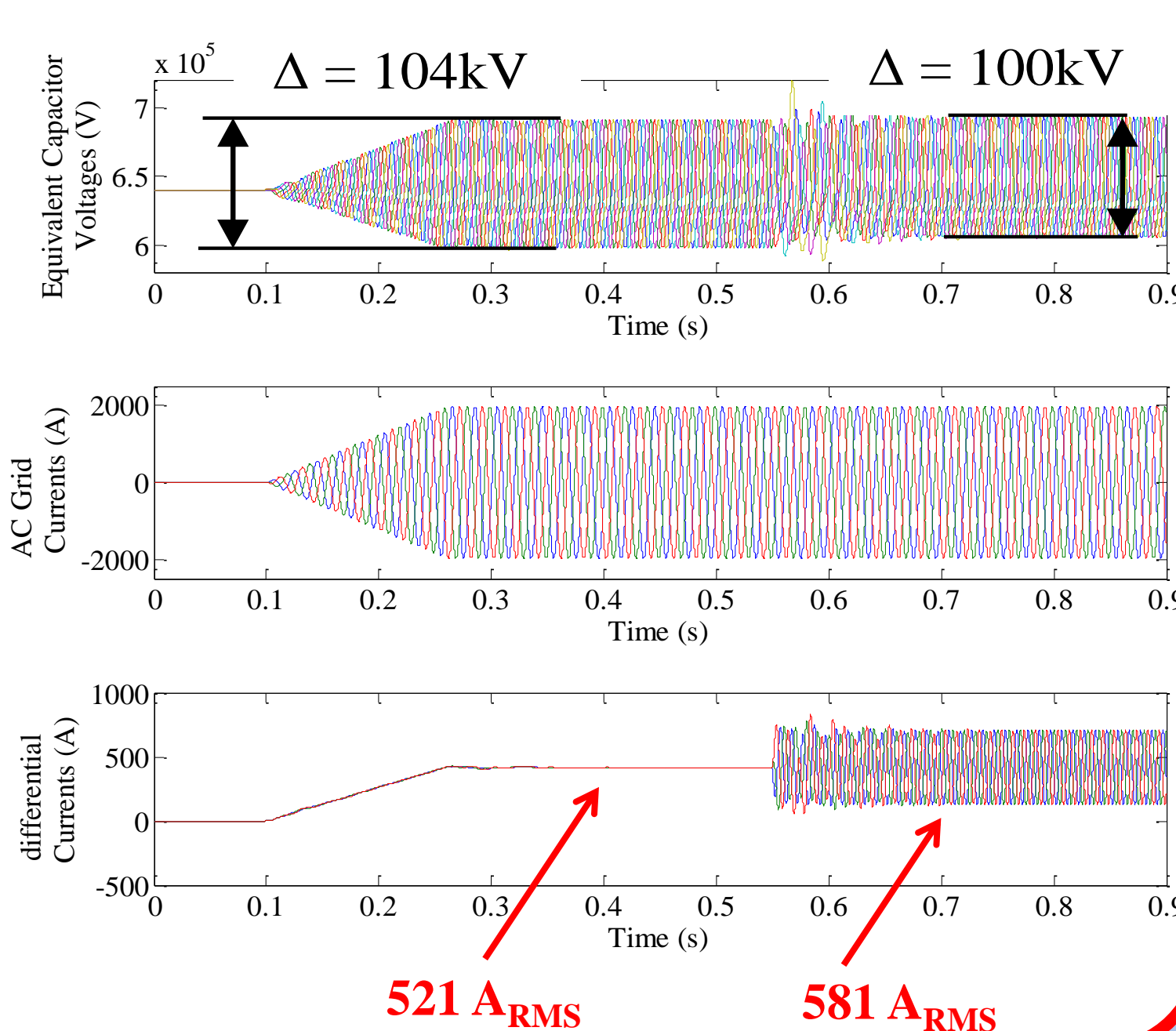
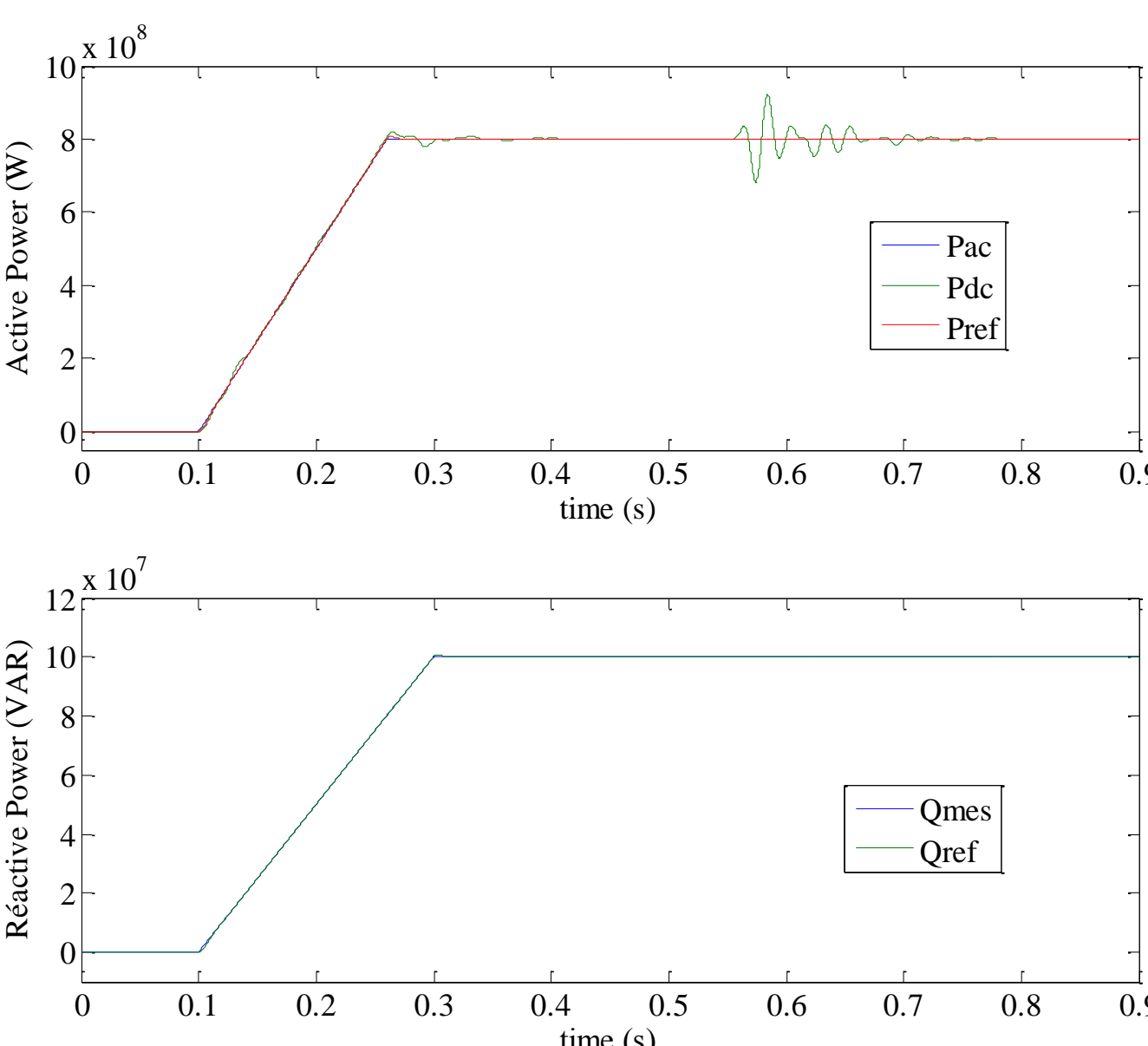
- IGBT conduction losses > diode conduction losses

the hypothesis of limiting the RMS current can be questionable.

Simulation Results

L	50 mH	C	10 mF
R	50 mΩ	N	400
L _{arm}	50 mH	V _{dc}	640 kV
R _{arm}	50 mΩ	ω	314 rad.s ⁻¹
S _N	1100MVA	V _g	192 kV
Tr _{igdq}	5ms	Tr _{ΣVei_tot}	50ms
Tr _{idiffi}	10ms	Tr _{ΔVei_tot}	100ms

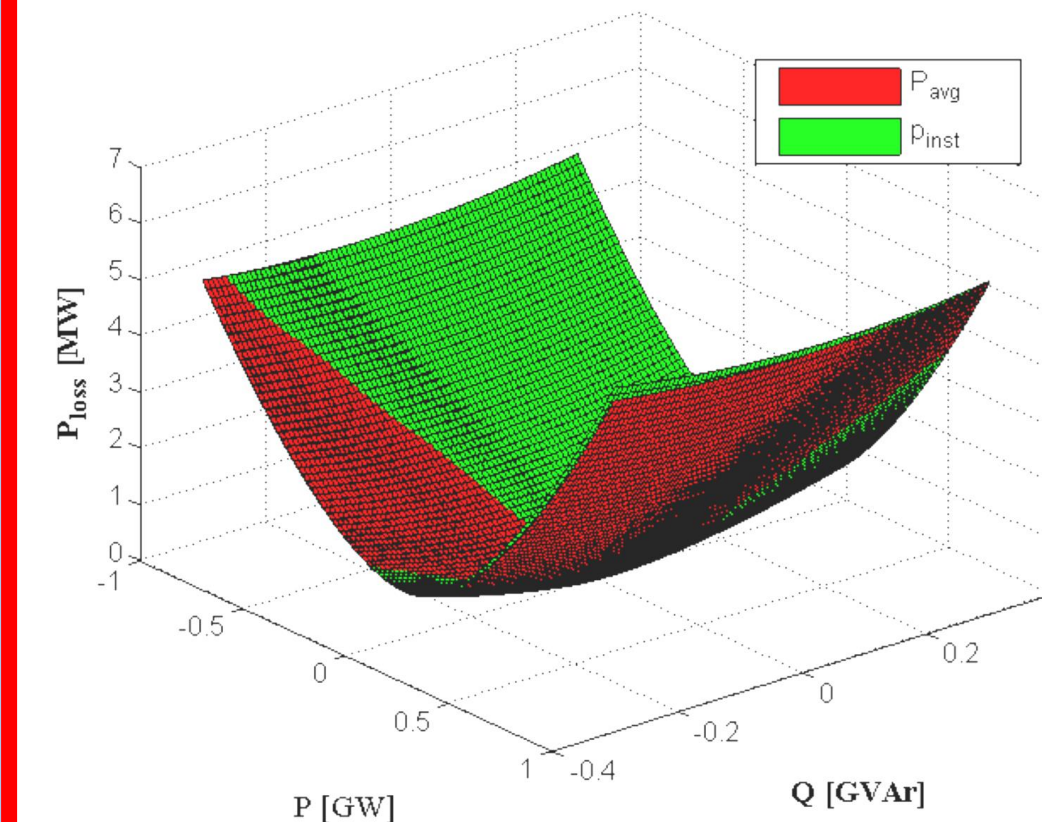
At t=0.1s : a slope is done in the AC power references (P_{ac}) equal to 0.8 GW and the reactive reference (Q_{ac}) to 100MVAR.
Before 0.55s, the Stored Energy control compensate the average power ($P_{ac}/3$)
After 0.55s, the Stored Energy control compensate the instantaneous one for each phase (p_{aci}).

**Simulation Losses Comparison Results**

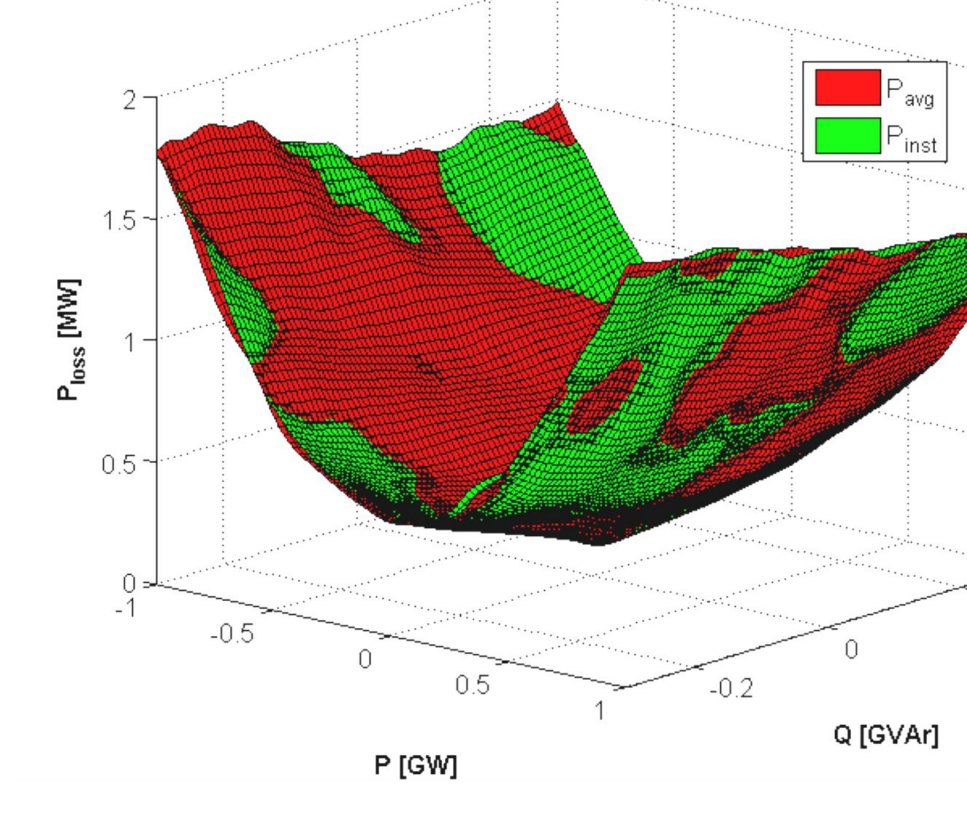
$$\blacksquare p_{ACi} = \frac{P_{AC}}{3} \quad \blacksquare p_{ACi} = \frac{P_{AC}}{3} + V_{gi} I_{gi} \cos(2\omega t + \varphi)$$

Conduction losses:

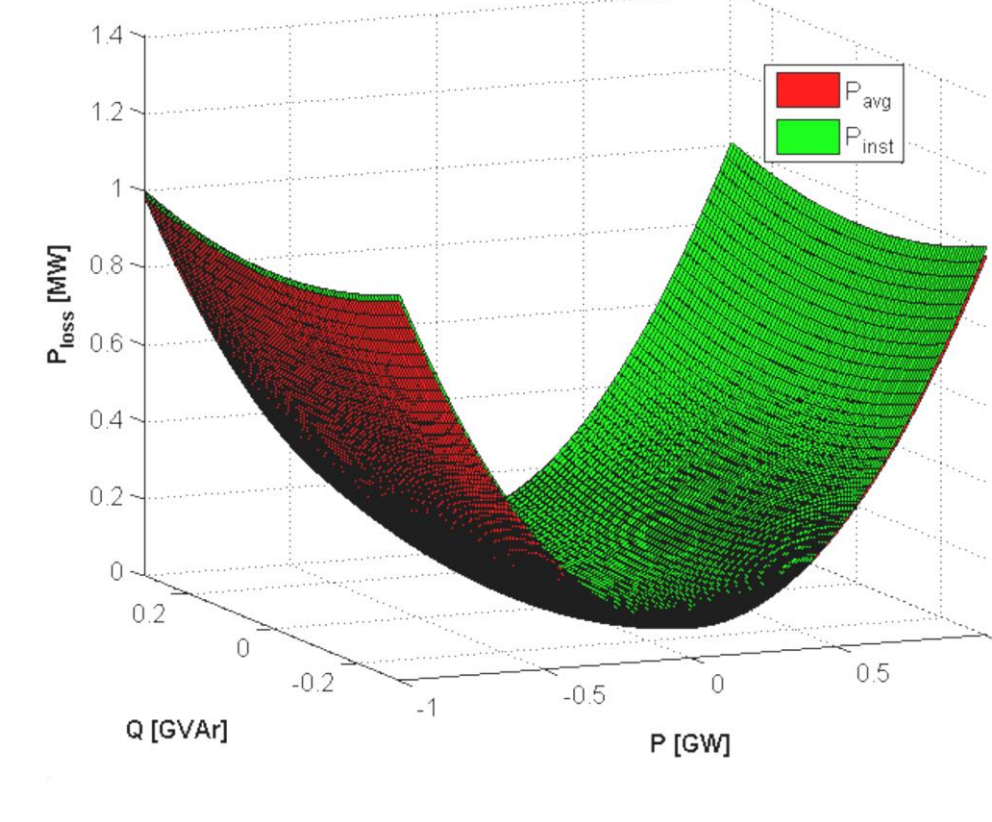
Conduction Losses - w/CM1500HC-66R (150 degrees)

**Switching losses:**

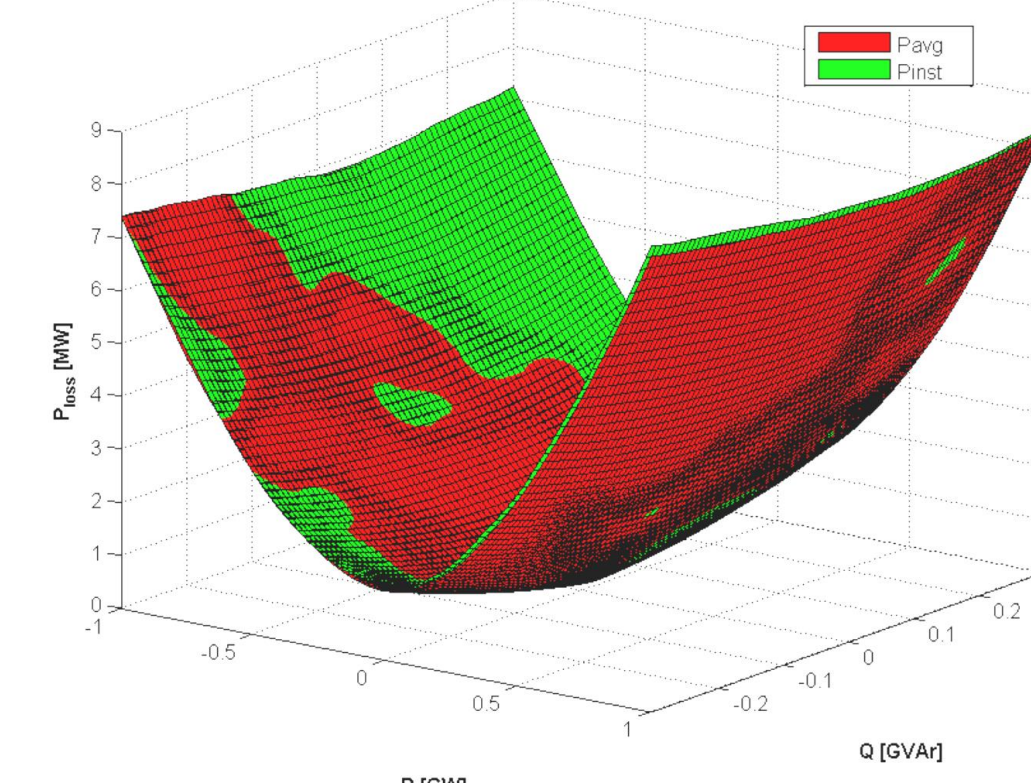
Switching Losses - w/CM1500HC-66R (150 degrees)

**Passive elements losses:**

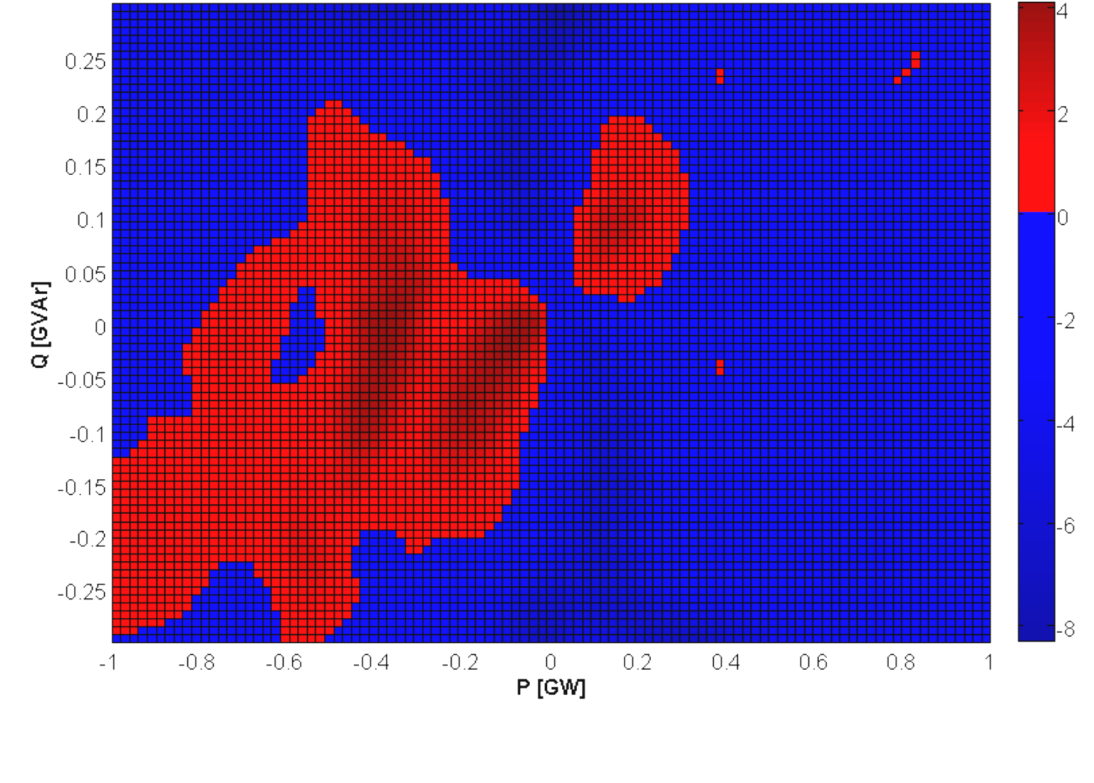
Passive Losses - w/CM1500HC-66R (150 degrees)

**Total MMC losses:**

Total Power Losses - w/CM1500HC-66R (150 degrees)



100*(P_avg/P_inst) - w/CM1500HC-66R (150 degrees)

**Conclusion**

- The impact of two control variants (compensation of the average or the instantaneous AC grid power) : differential and AC grid currents, capacitor voltages ripple, losses.

• **compensation of the average AC grid power:**

- differential currents are constant
- V_{c_tot} ripple are 4% higher

• **Losses**

Usual assumption is not every time validate

• **compensation of the instantaneous AC grid power:**

- differential currents have DC and AC components at 2ω
- RMS differential currents is 11% higher

the MMC converter using considerable number of semiconductor; the losses are not only related to the RMS current value but also to the way of this current (diode or IGBT) → therefore to the control