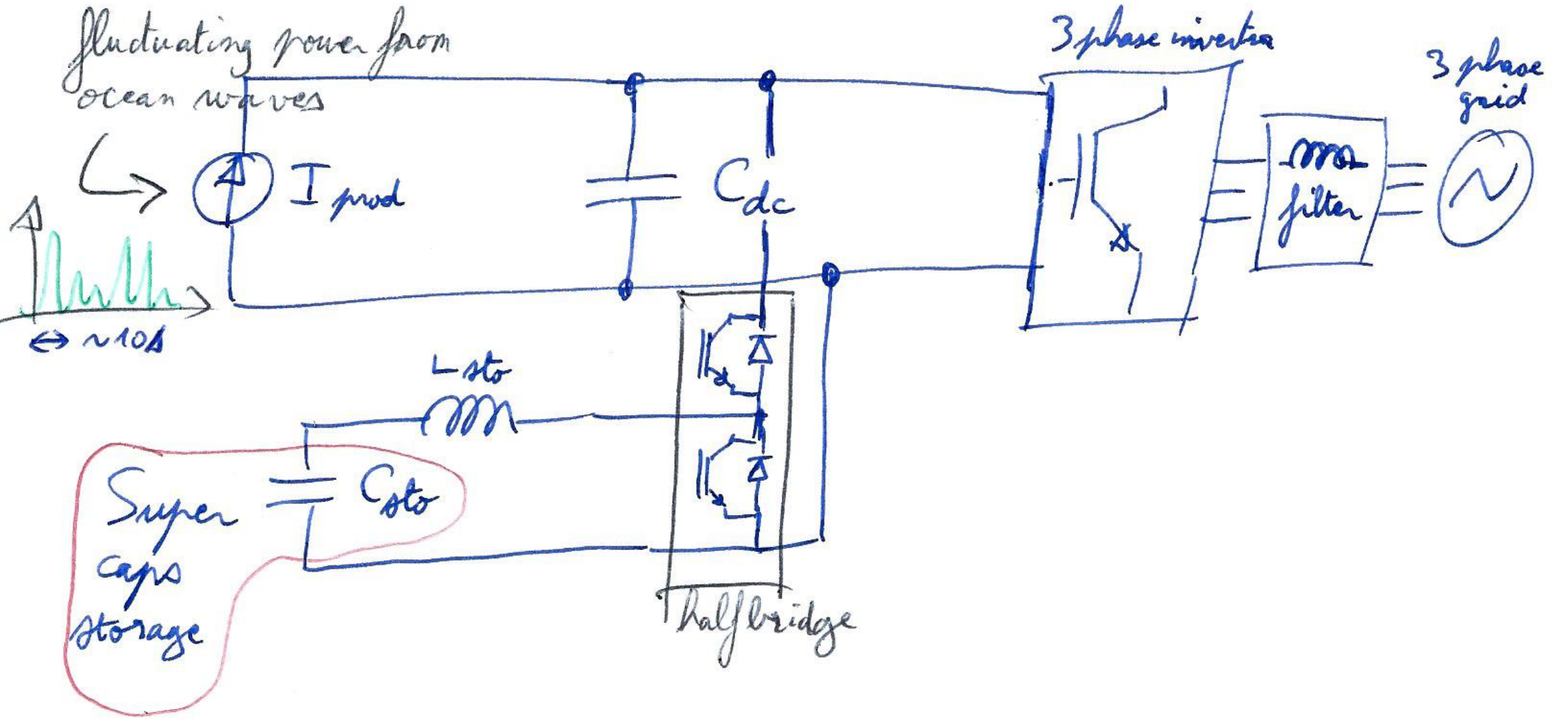
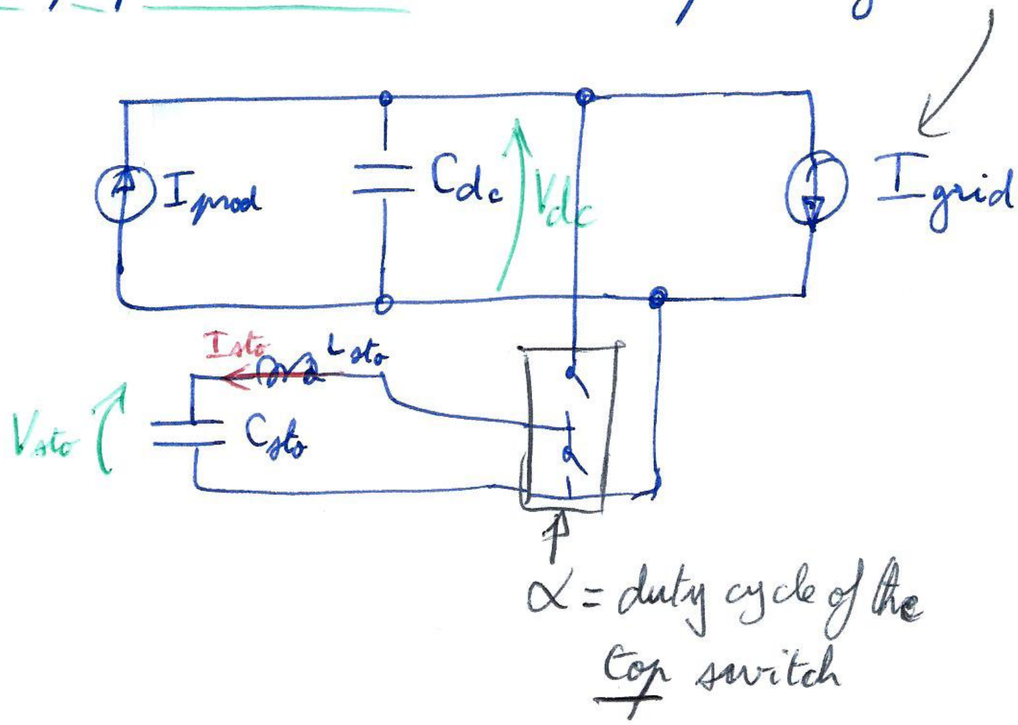
DSP-based control of an ESS (super caps) for power smoothing

Complete circuit:



Simplified circuit: inverter replaced by a current source



State equations of the simplified circuit: (averaged over PWM period)

① DC bus capa: $$C_{dc}\frac{dV_{dc}}{dt} = +I_{prod} - I_{grid} - \alpha I_L$$

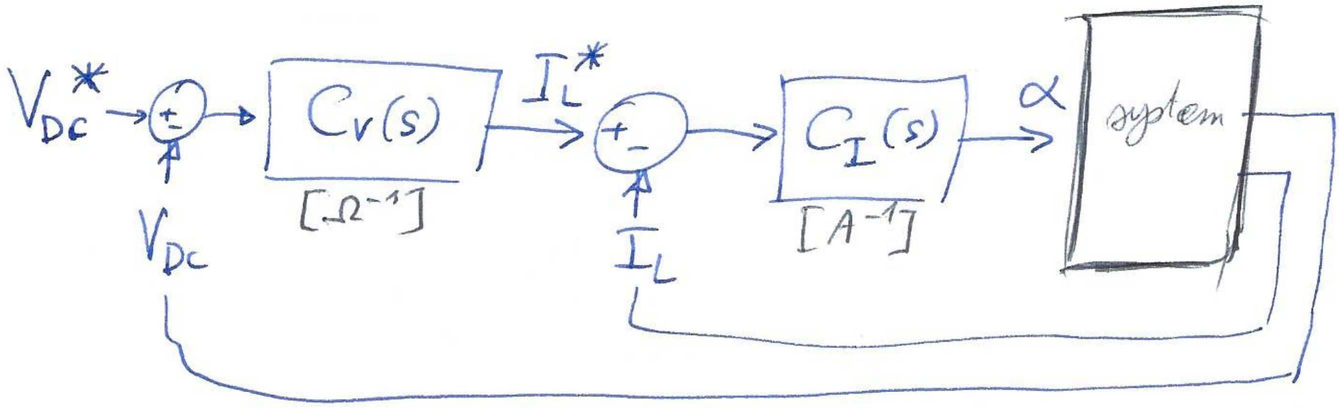
② Super capa: $$C_{sto}\frac{dV_{sto}}{dt} = +I_L$$

③ Smoothing inductor: $$L_{sto}\frac{dI_L}{dt} = \alpha V_{dc} - V_{sto}$$

↳ block diagram model with 3 integrators. (in Simulink)

control variable: duty cycle α | Control objective: regulate V_{dc}

Proposed control strategy: voltage and current loop.



Rough sizing of the electrical system

- **DC bus voltage**: 1300 V $\rightarrow V_{DC}^{*}$

  ↳ consequence: peak current $I_{prod}^{max} = \dfrac{1{,}1\,MW}{V_{DC}} \simeq 850\,A$

- **supercaps sizing**:

  useable energy: $E_{rated} = \dfrac{1}{2} C_{sto} \left(V_M^2 - V_m^2\right)$

  ↳ hypothese: $V_m = V_M/2 \rightarrow E_r = \dfrac{3}{8} C_{sto} V_M^2$

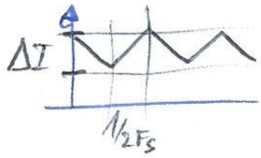
  ↳ $C_{sto} = \dfrac{8}{3} \dfrac{E_{rated}}{V_{max}^2}$

  with $\begin{cases} E_r = 10\,MJ & \text{(cf. EuroSailing article)} \\ V_{max} = 1300\,V \end{cases} \rightarrow C_{sto} \simeq 16\,F$

- **Switching frequency**: $F_S = 2\,kHz$ (from previous studies)

  consequence on inductance sizing: (current ondulation)

  $\Delta I = \dfrac{V}{L \cdot 2F_s}$ (at $\alpha = 1/2$)



  ↳ $L = \dfrac{V}{2F_s \cdot \Delta I} \simeq 3\,mH$ for $\Delta I = 100\,A$

- **DC bus capacitor**: should buffer the current pulses from the inverter.

  $C\Delta V = I\Delta t = I/2F_s \rightarrow C_{dc} = \dfrac{I}{\Delta V \cdot 2F_s} = 25\,mF$ for $\Delta V = 10\,V$