Advanced Control Design for Multi-terminal HVDC Power Systems

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Introduction

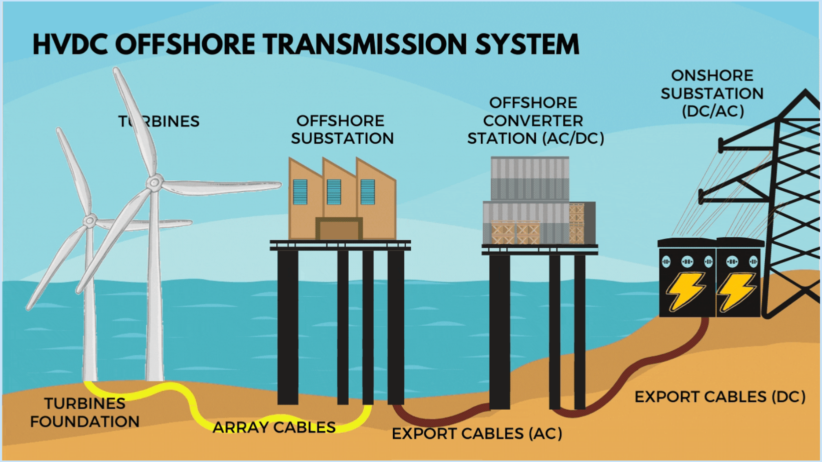
Necessity for HVDC:

- EU ambition: 80-95% CO_2 reduction in 2050 compared with 1990 levels.
- Large volumes of RES needed in NL:
  - 2000 GW of sun PV required to cover 50% of the electricity demand (TU Delft).
  - 600 GW offshore & onshore wind power required to cover 50% of the electricity demand (EWEA).

HVDC is beneficial since:

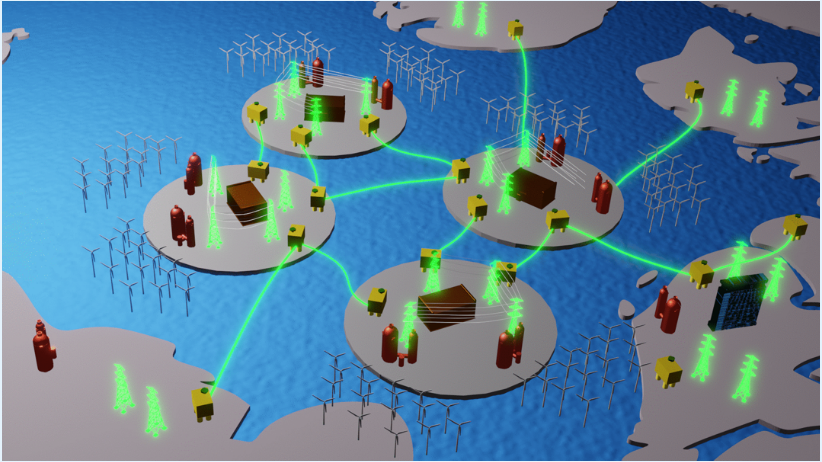
- It does not require three conductors.
- There are no reactive components.
- Easier control design.

Offshore HVDC power system[a]



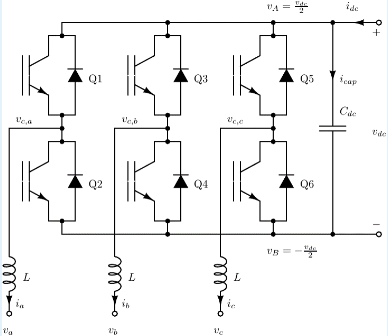
[a] © The Biggest Challenge for Offshore Wind, Prospero Events Group, www.virtual.prosperoevents.com/blog/the-biggest-challenge-for-offshore-wind

There is need for energy hubs and multi-terminal HVDC connections.

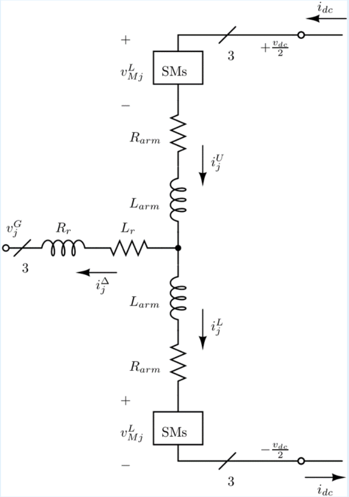


VSC design

Two level Voltage Source Converter



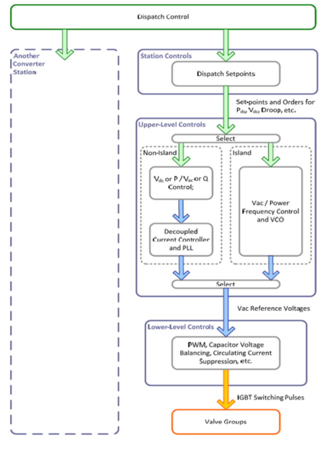
Modular Multilevel Converter



VSC control design

CIGRE control settings[a]

[a] e-cigre.org (2013). The CIGRE B4 DC grid test system. Vrana et. all



- Inner controlling loops are the same.
- Outer loops differ.

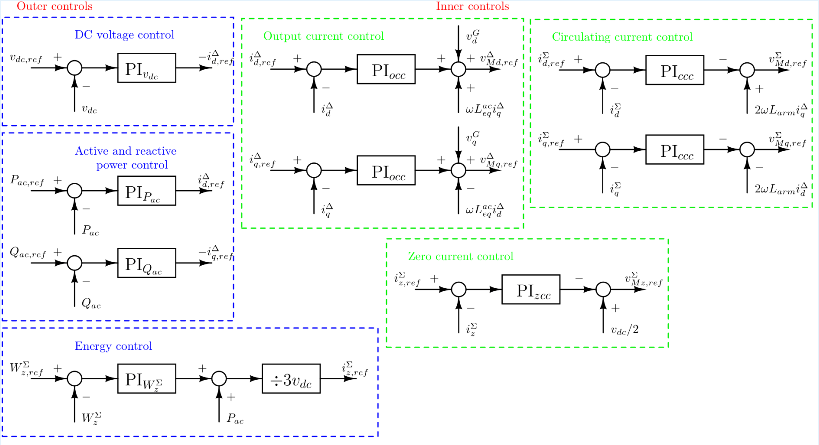
Offshore converters (island)

- AC voltage or active power control.
- Frequency control with PLL.

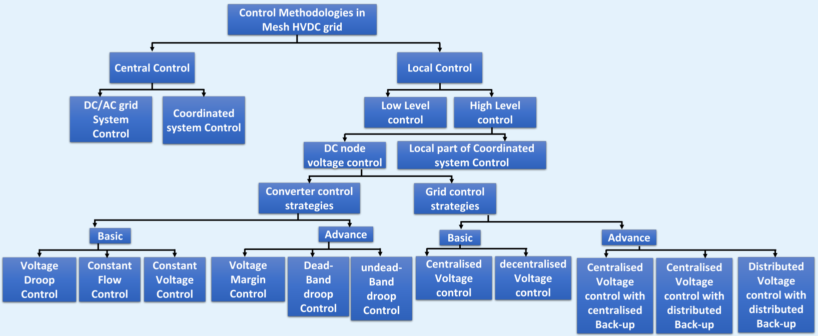
Onshore converters (non-island)

- DC voltage or active power control.
- AC voltage or reactive power control.

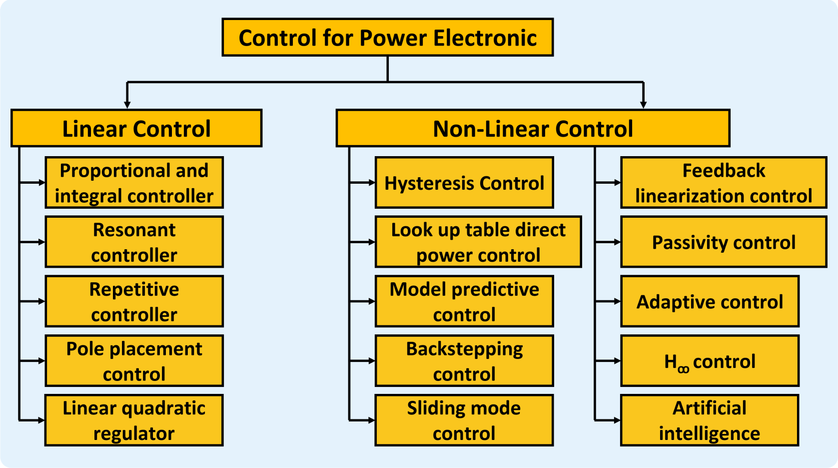
MMC control - classical approach



Advanced control approaches for MTDC 1/2



Advanced control approaches for MTDC



Model Predictive Control

MPC formulation

$$\min_{\vec{\eta}} J = \sum_{m=1}^{N_p} \vec{x}(k+m|k)^T Q \vec{x}(k+m|k) + \vec{\eta}^T R \vec{\eta},$$

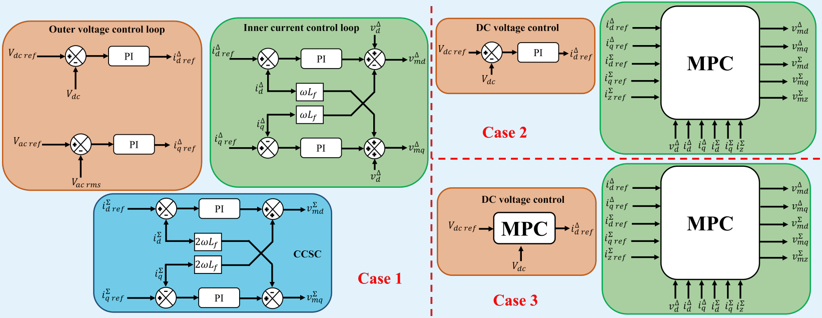
$$\text{subject to } M\vec{\eta} \leq b,$$

$$\vec{x}(k+m|k) = \vec{r}(k) - \vec{y}_m(k+m|k),$$

where:

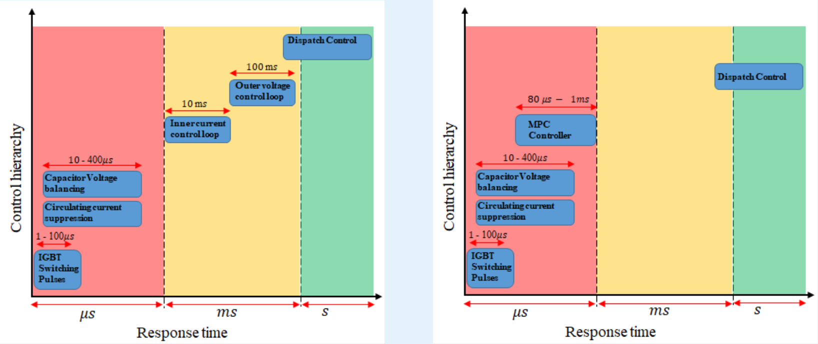
- $\vec{x}$ represents state variables;
- $\vec{r}(k)$ is a reference signal;
- η is calculated by minimising the objective (cost) function;
- $\vec{y}$ represents outputs;
- R, Q, M, and b are corresponding matrices and vector.

Different study cases

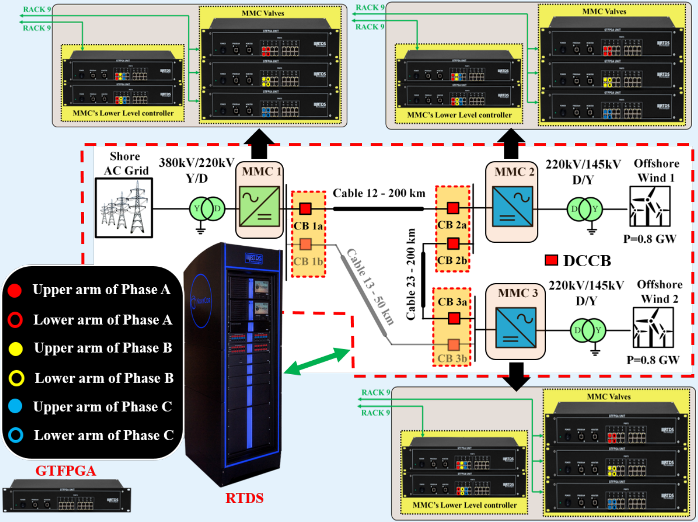


Use of MPC for MTDC control 2/6

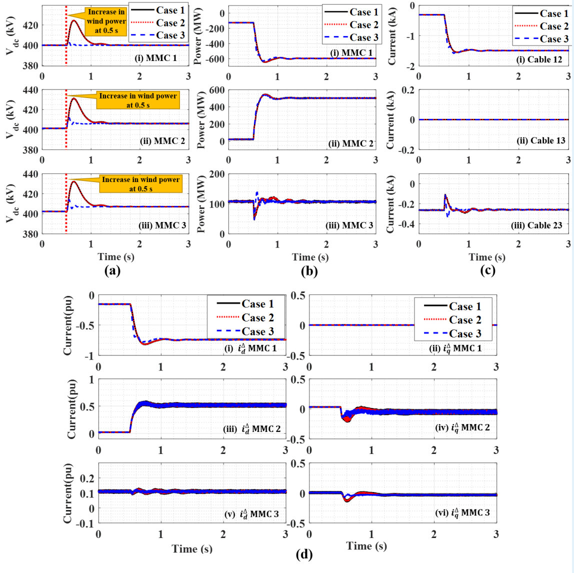
PI-left and MPC-right RTDS processor time allocation



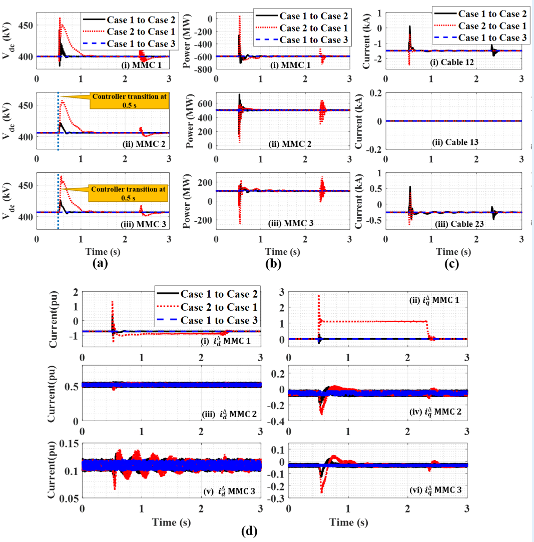
Test setup in RSCAD/RTDS



Interoperability PI-MPC: Behavior after wind speed change



Interoperability PI-MPC: Effect of transition between controllers



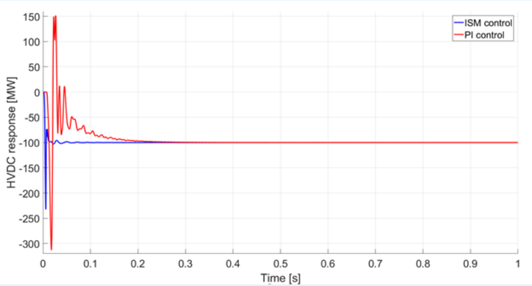
Conclusions

- The fast power flow injection increases DC voltage in the presence of slow controllers (PI), but not when MPC is used.
- A major setback was observed during transition between MPC and PI controller.
- MPC is computationally efficient and can produce output within one time interval in real-time simulation.

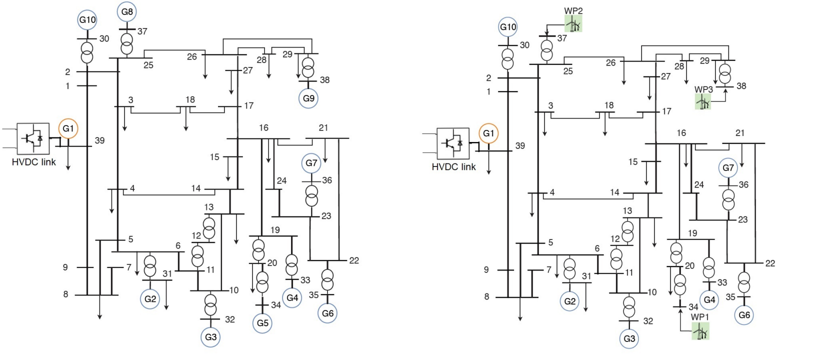
Use of Sliding-Mode Control (SMC)

Control settings

- PI controls for circulating/zero/output current control, and zero energy control.
- Integral SMC active/reactive power control, defined with sliding surface:
  - $S(i^{\Delta}_{d,q}) = i^{\Delta}_{d,q,ref} - i^{\Delta}_{d,q}$,
  - $\dot{S}(i^{\Delta}_{d,q}) = -\dot{i}^{\Delta}_{d,q} = -\sqrt{U}\sqrt{|x^{\Delta}_{d,q}|}\,\mathrm{sgn}(x^{\Delta}_{d,q}) - 1.1U\,x^{\Delta}_{d,q}$, with $U > 0$ and $x_{d,q}$ being the outputs of the output current controller.



Test system - IEEE 39 bus

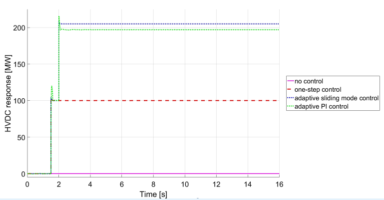


a) Configuration I b) Configuration II

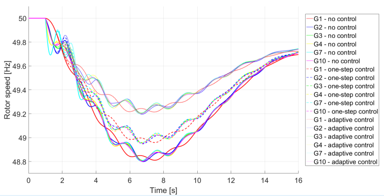
Test case: adaptive control of HVDC links for frequency stability enhancement

Use of SMC 3/3

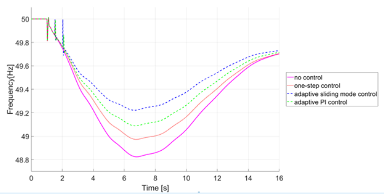
Reaction to large disturbance - tripping of G6 with approx. 800 MW loss



Power



Generators' rotor speed



Frequency

Conclusion

This presentation

- Describes potential for advanced controls in MTDC.
- Two test cases are given:
  - MPC for onshore converters and reaction to wind speed change and transition between controllers.
  - Role of SMC for adaptive control of HVDC links for frequency stability enhancement.
- There is much more...

Thank you for your attention!

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