InnoDC
INNOVATIVE TOOLS FOR OFFSHORE WIND AND DC GRIDS

Comparison of Grid forming control strategies in the scope of BSR by OWPPs

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PhD:

Blackstart & Islanding capabilities of Offshore Wind Power Plants

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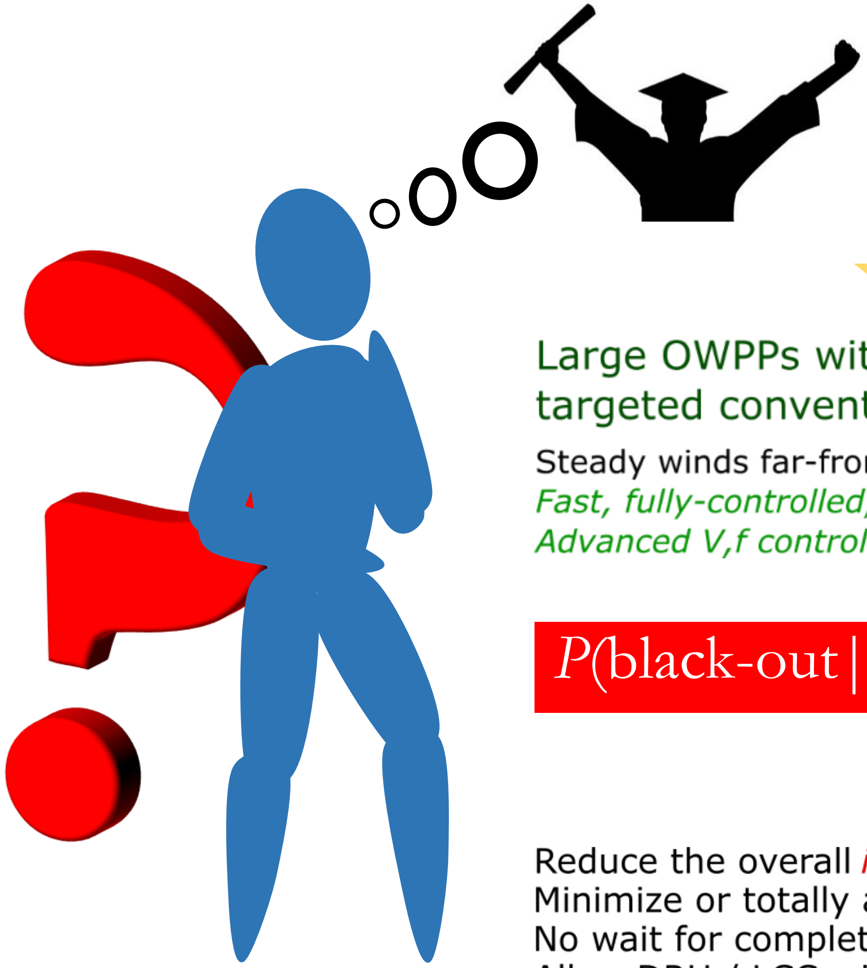
Motivation



Increased risk of wide-area blackouts [1]

High volume integration of RES far from loads
Increased trans-national power exchanges
Power electronics converter (PEC) interface
Stronger network linking

} *Operation closer to dynamic stability limit*

Large OWPPs with modern WTs can address Blackstart requirements targeted conventionally to large thermal plants: ENTSO-E codes

Steady winds far-from-shore, thus *lesser availability-uncertainty*
Fast, fully-controlled, high-power environment-friendly BS capability of VSC-HVDC OWPP
Advanced V,f control functionalities from state-of-art PE interface of modern WTs

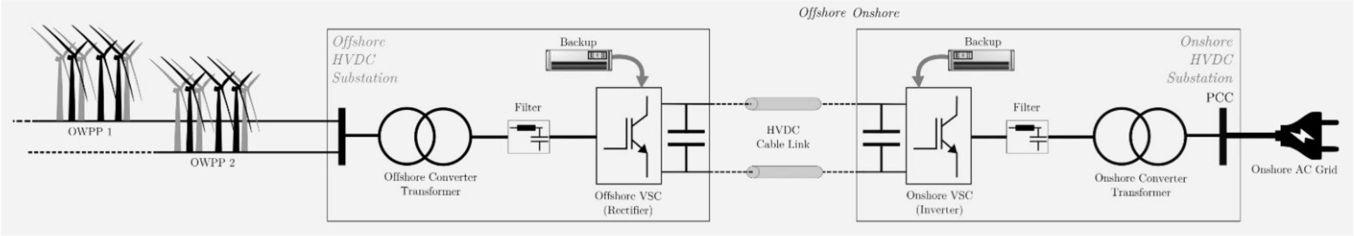
$P(\text{black-out} \mid \text{no-wind}) \rightarrow \text{LOW}$

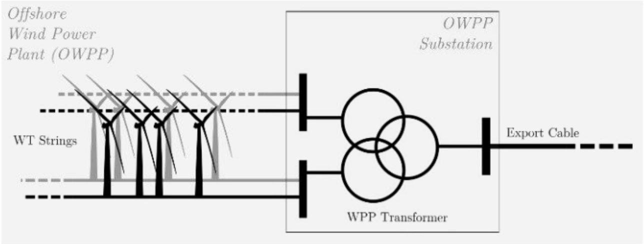
Grid forming WT,WPPs

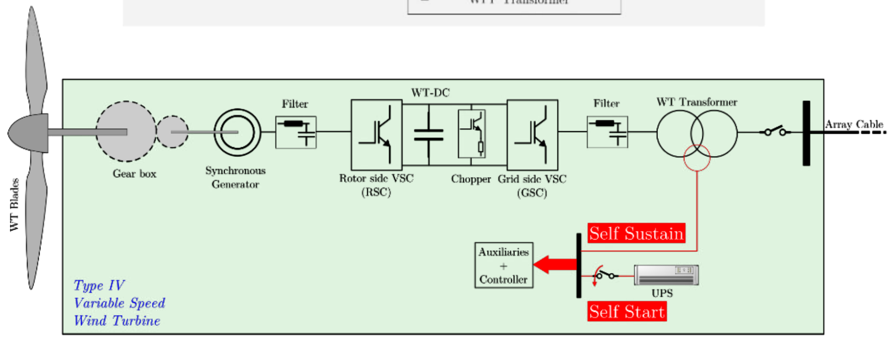
Reduce the overall *impact* of a blackout event
Minimize or totally avoid use of *backup diesel generator* for auxiliary power, thus cost benefits
No wait for completion of network reconstruction; *controlled islanding* to ensure continuity of power supply
Allow DRU / LCC-with-smaller-filter, thus reduce costs, increase efficiency & reliability

Target State 1

- *Housekeeping* – internal UPS / BESS [2]
- Grid forming [3] GSC + RSC
- Down-regulation: Power-curtailment / Idling modes

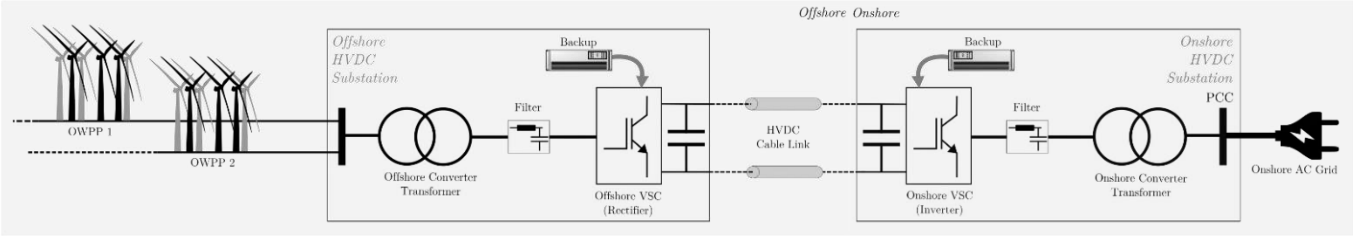


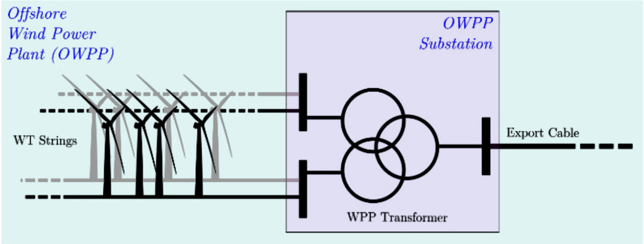


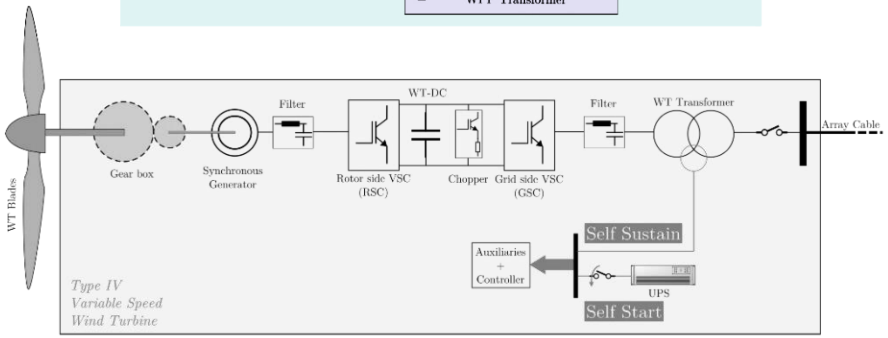


Target State 2

- Voltage controlled island – 3-level µGrid control [4] + MMO [5]
- Grid-formers : Grid-followers
- STATCOM mode – VAR compensation [5]
- Intelligent control-mode switching [6]

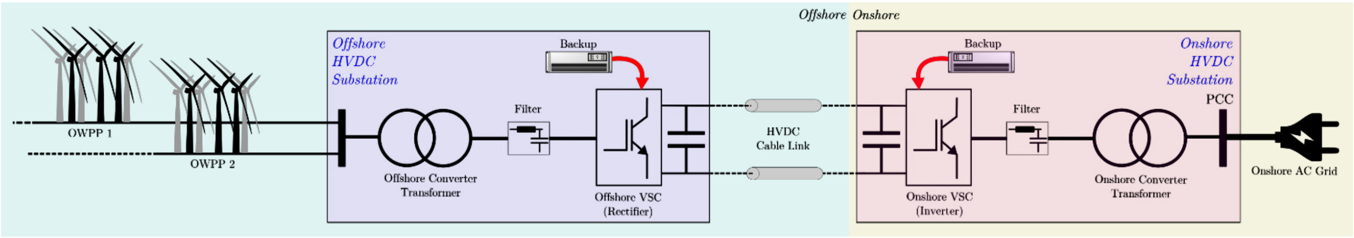


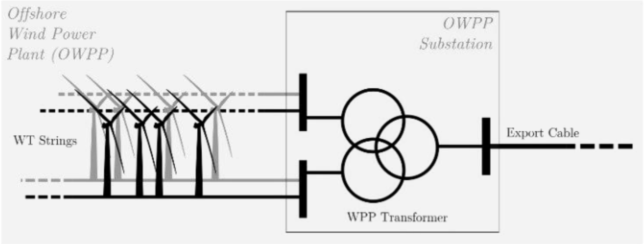


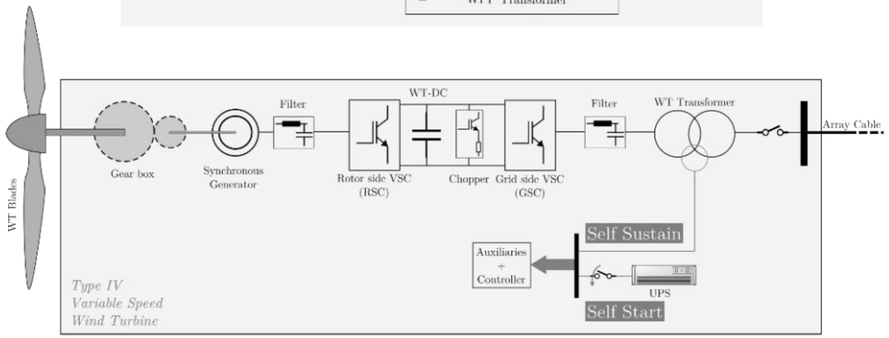


Target State 3

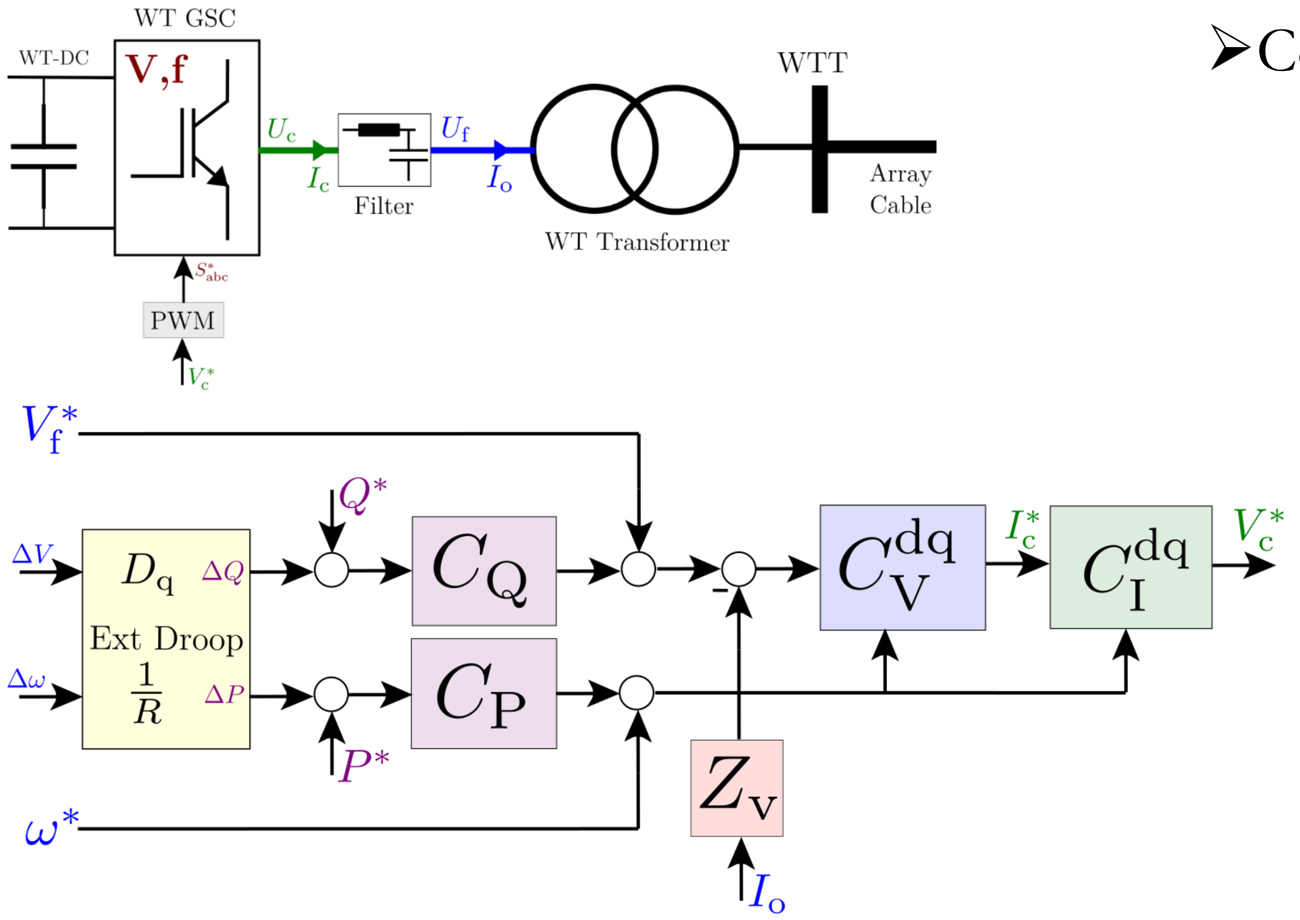
- *Stiff, controlled* Voltage source – WPPs coordinated parallel operation
- Controlled Islanded Operation: stability & robustness
  - Offshore & DC grid faults
  - Harmonic instabilities [7]
  - HVDC link resonance issues [8]
  - Substantial network configuration changes [9] eg. load pickups, WT connections/disconnections





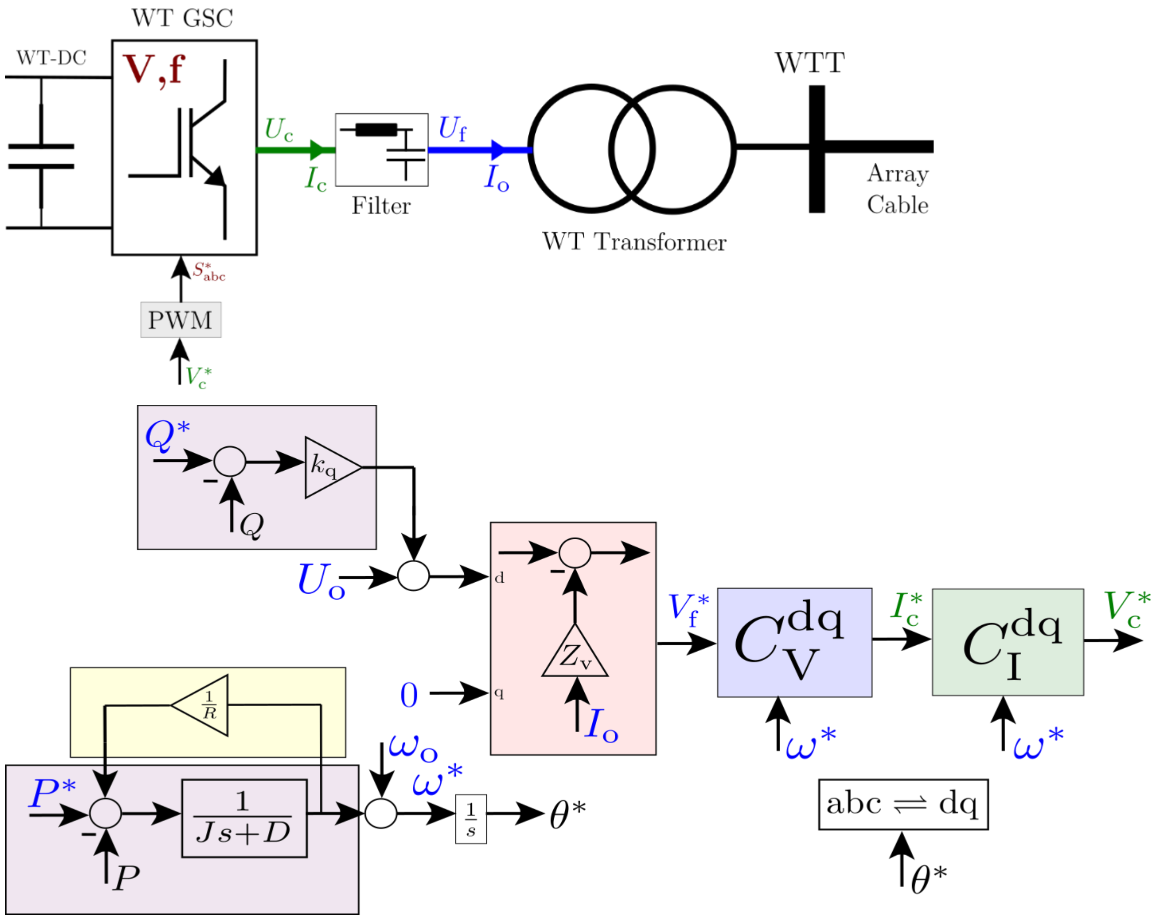


Grid forming WT (TS1) [3]



- Controls *V,f* at WTT
  - Inner loops - dq
    - Ci: limit current during transients/faults.
    - Cv: control WTT V
  - Outer loops - Droop/VSM(v J,D)/PI/LL
    - Cq: QLC
    - Cp: PLC
  - Additions
    - Ext f-P droop (~1/R in SG)
    - Ext V-Q droop (~AVR in SG)
    - Virtual impedance (single/multiple *f*) to damp inrush/OC/harmonics.

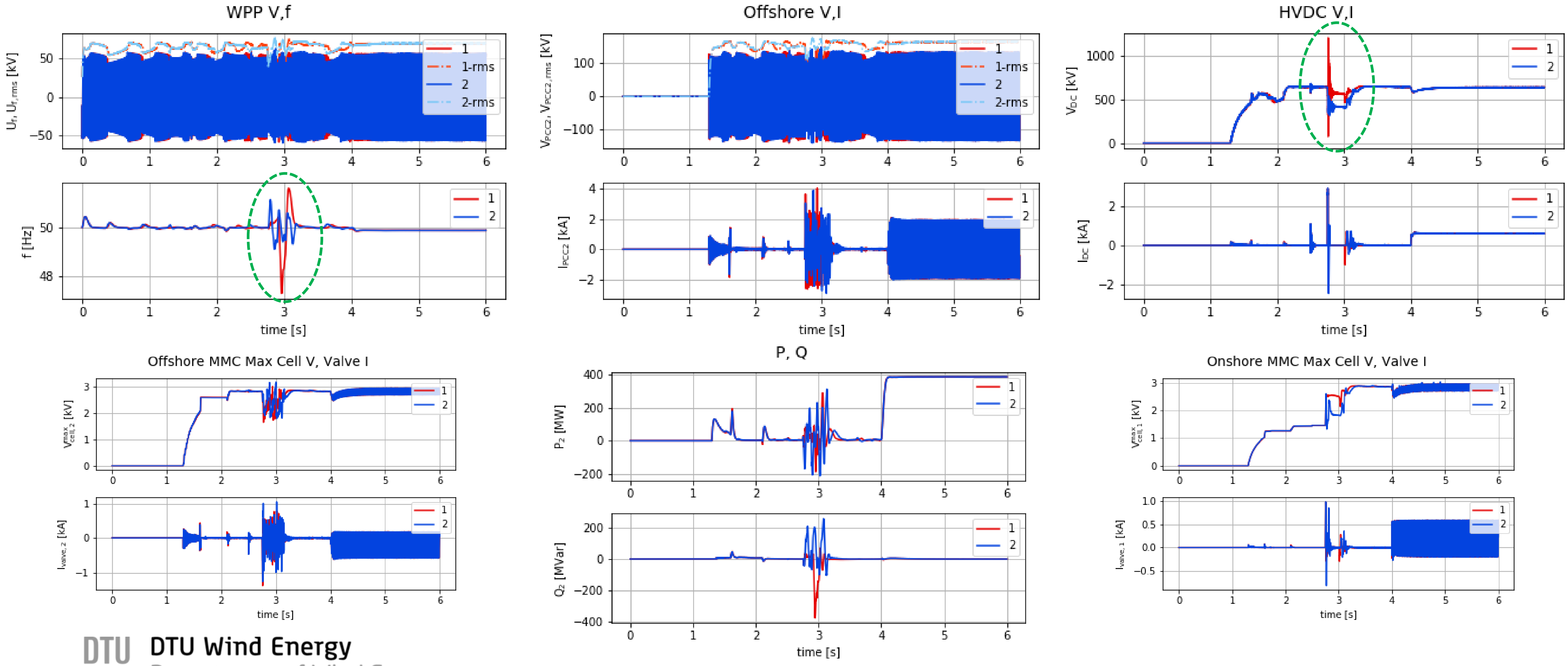
VSG [11]



- Q-V & P-f (~SM)
- QLC: Q-V droop
- PLC:
  - VSM (virtual J, D)
- Addition [12]:
  - Ext *f*-*P* droop
  - Virtual admittance
  - ~~Active damping~~

Comparison

1. VSG without external f-P droop
2. VSG with external f-P droop



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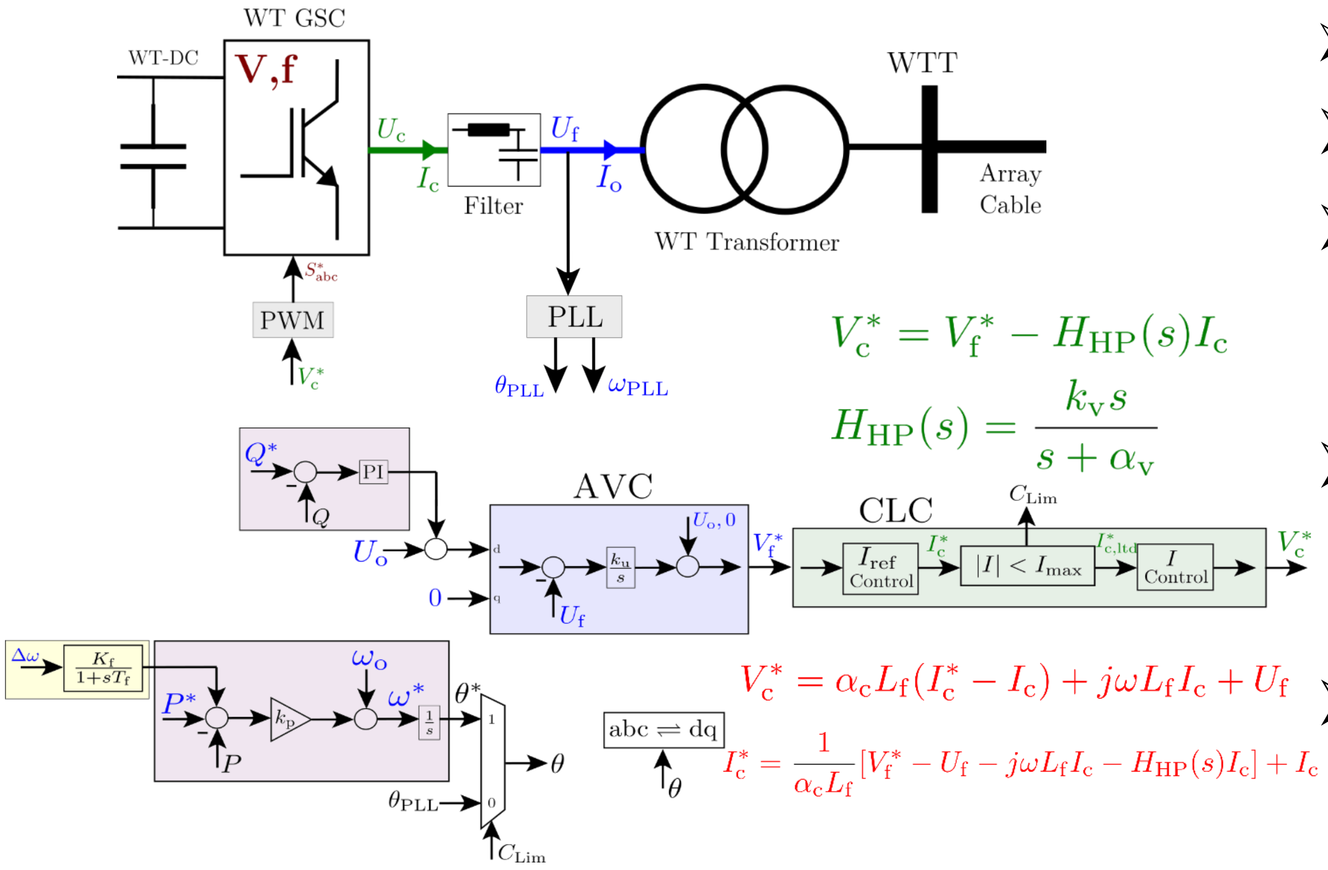
PSC [13]



$$V_c^* = V_f^* - H_{HP}(s) I_c$$

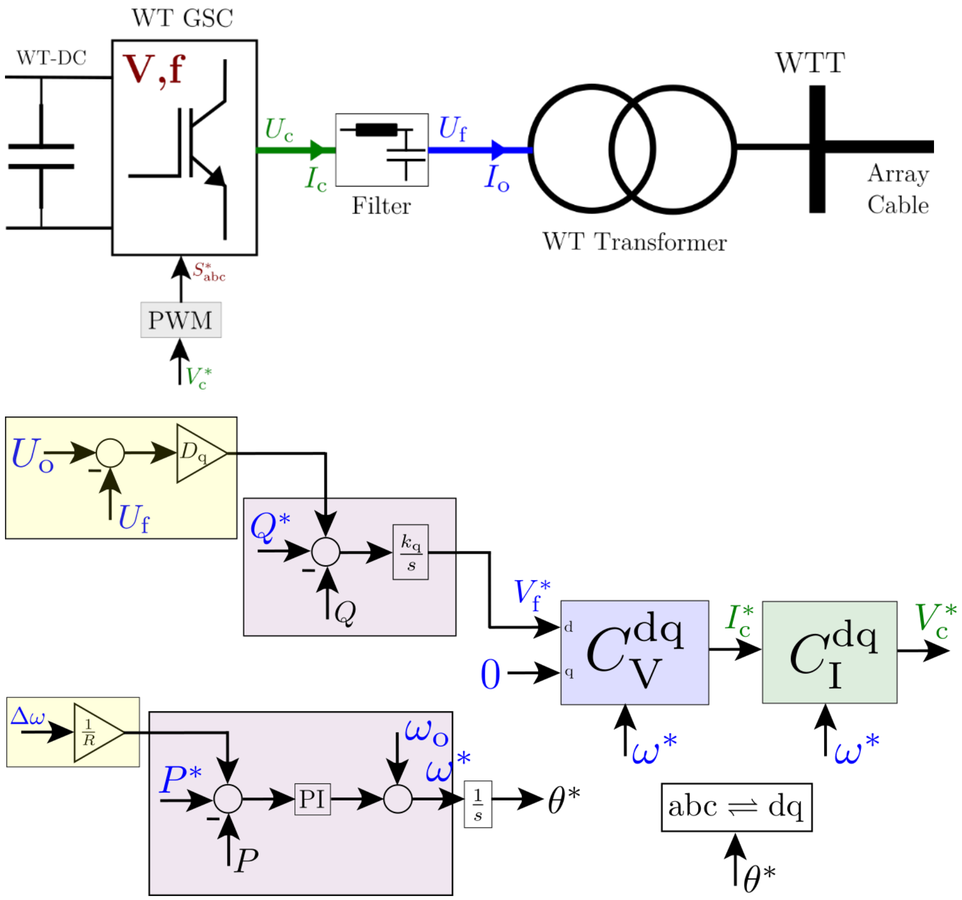
$$H_{HP}(s) = \frac{k_v s}{s + \alpha_v}$$

$$V_c^* = \alpha_c L_f (I_c^* - I_c) + j\omega L_f I_c + U_f$$

$$I_c^* = \frac{1}{\alpha_c L_f}[V_f^* - U_f - j\omega L_f I_c - H_{HP}(s) I_c] + I_c$$

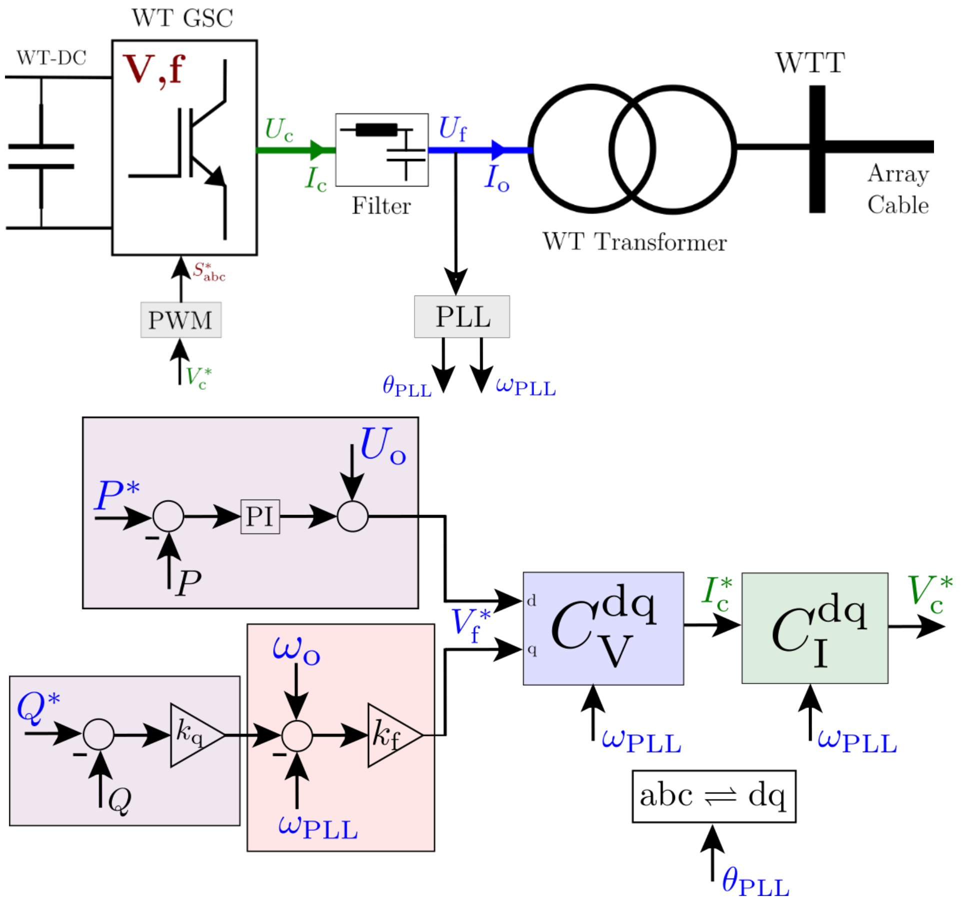
- Q-V & P-f (~SM)
- PLC: P
- AVC: (~ SM exciter, but I & not P)
  - Reqd for weak grids/islands
  - Optional: QLC (PI).
- CLC:
  - Normal mode: ~active damping (HF:R)
  - Faults: OC limit & switch to PLL
- Proven response for weak grids.

DPC [14]



- Q-V & P-f (~SM)
- QLC: I
- PLC: PI
- Addition:
  - Ext V-Q droop
  - Ext f-P droop
- Faults: current limitation ~ PSC

Distributed PLL [15]

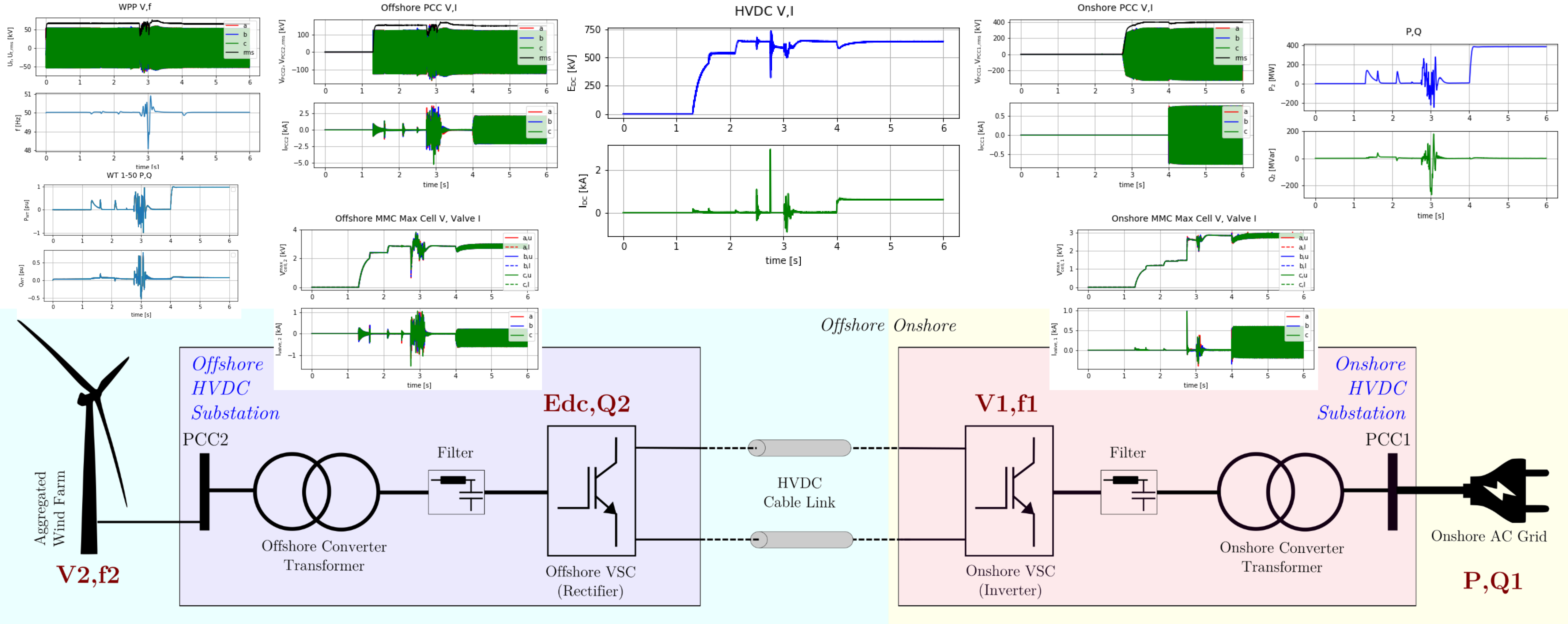


- PLC: PI
- QLC: P
- Addition:
  - PLL based fLC:

$$V_{fq} > 0 \Rightarrow f > f_0$$

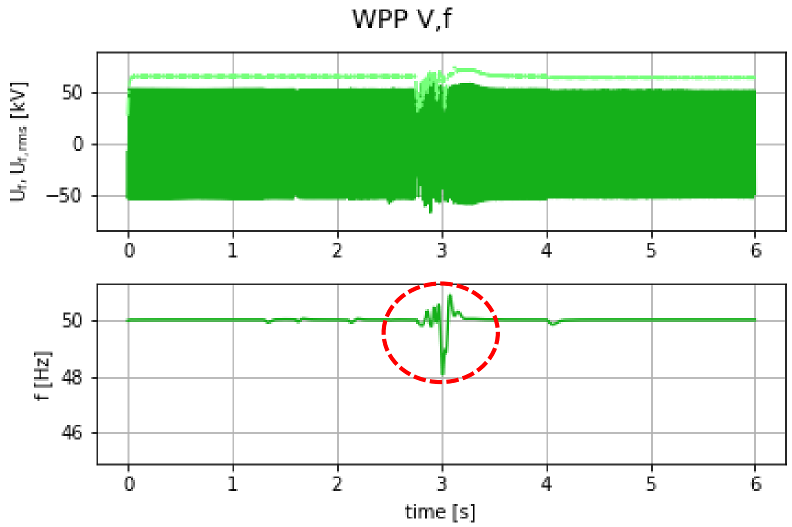
Thus, $V^*_{fq} = k_f(f_{\mathrm{ref}} - f)$

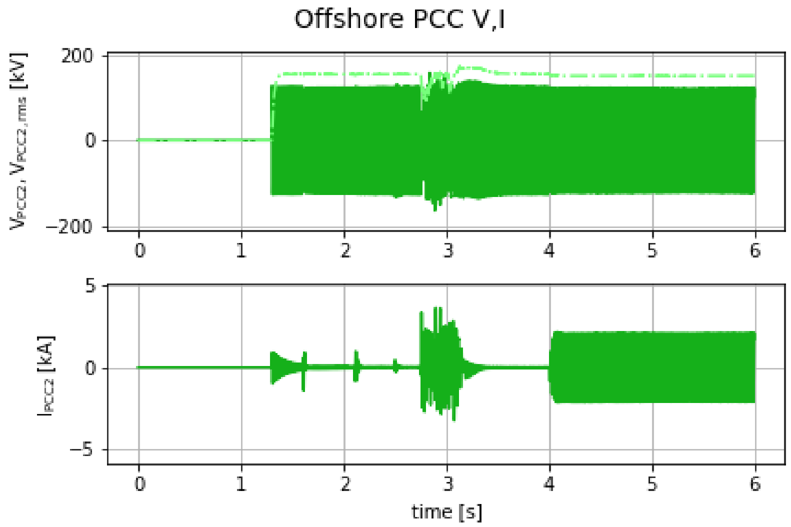
BSR (Distributed PLL)

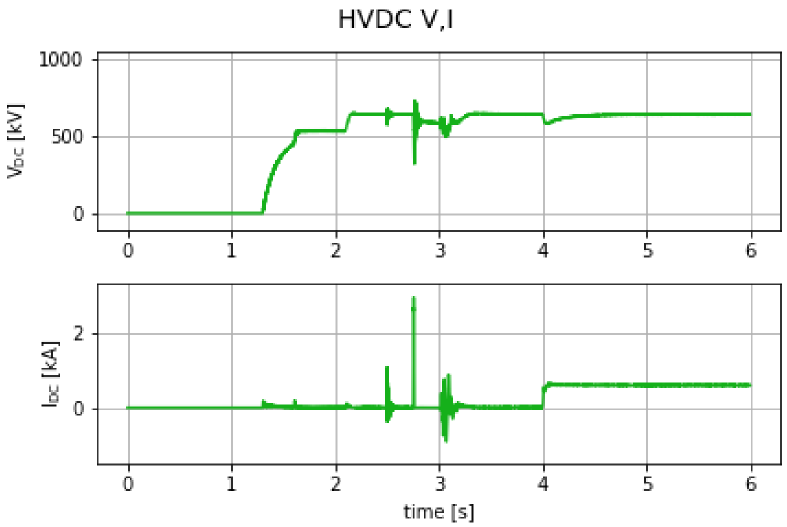


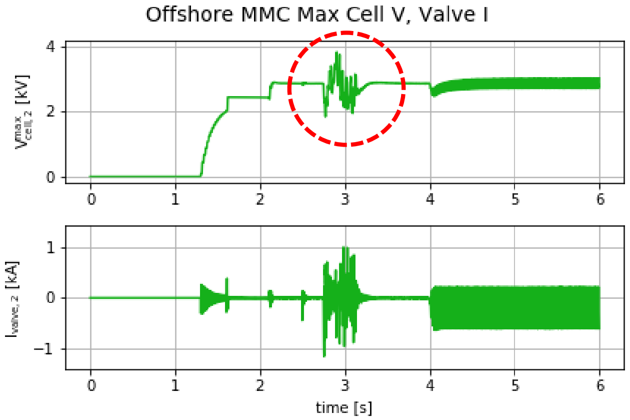
Comparison

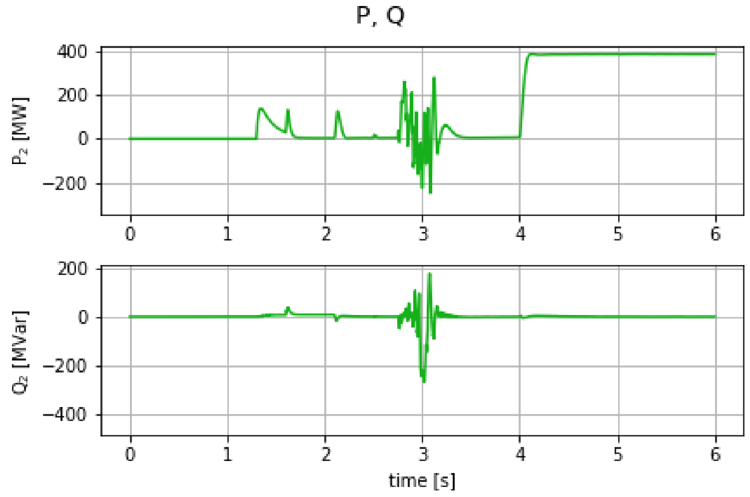
1. **Distributed PLL**
2. VSG
3. DPC
4. PSC

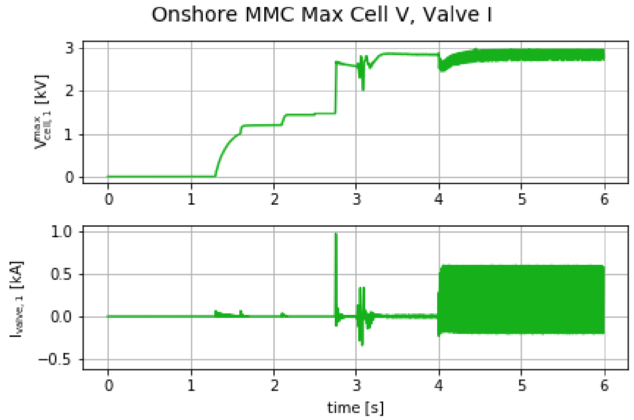






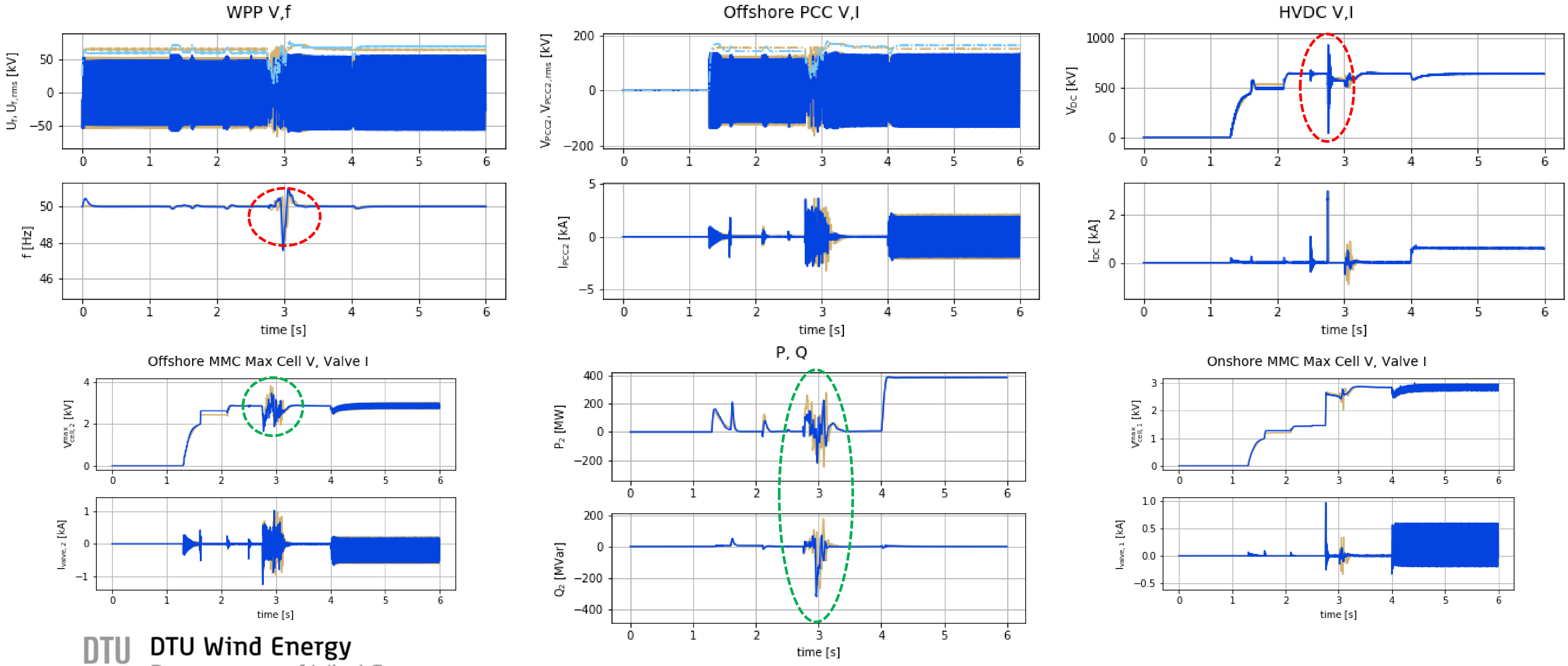






Comparison

1. Distributed PLL
2. VSG
3. DPC
4. PSC



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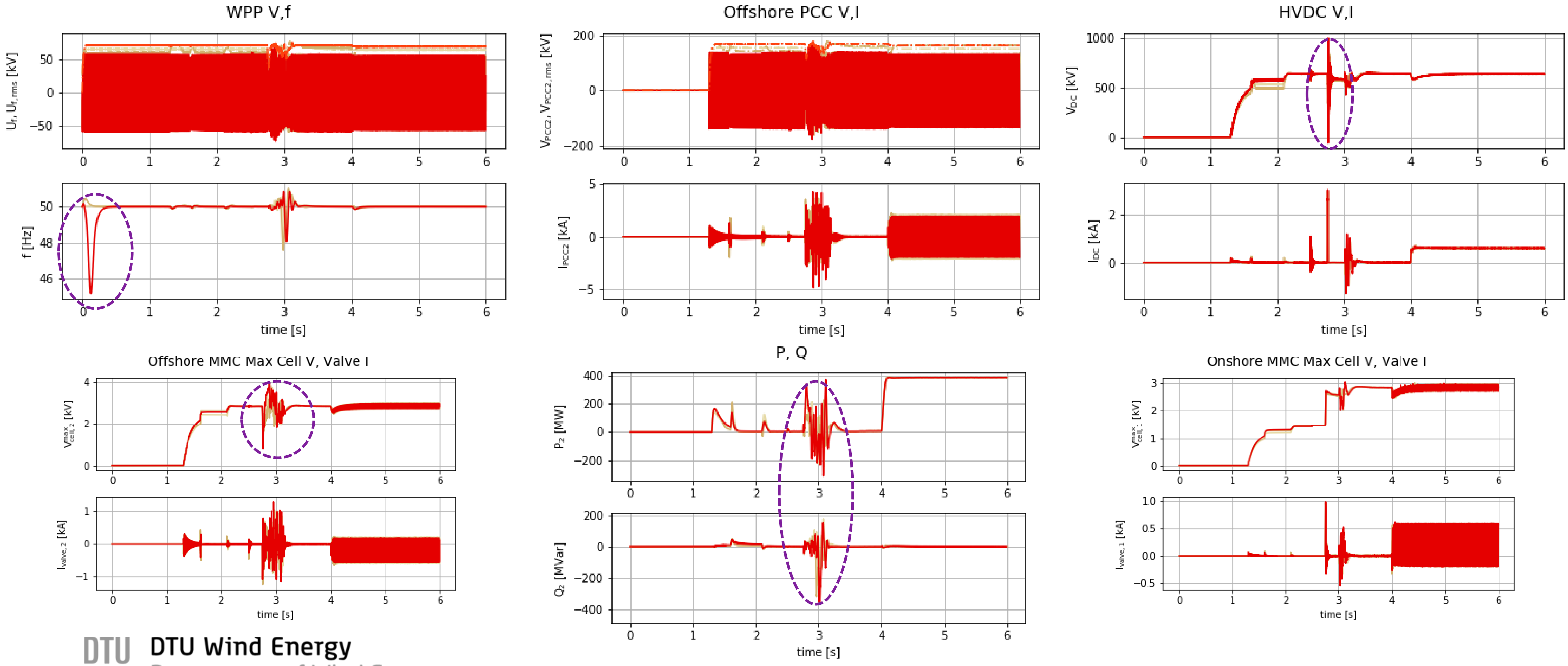

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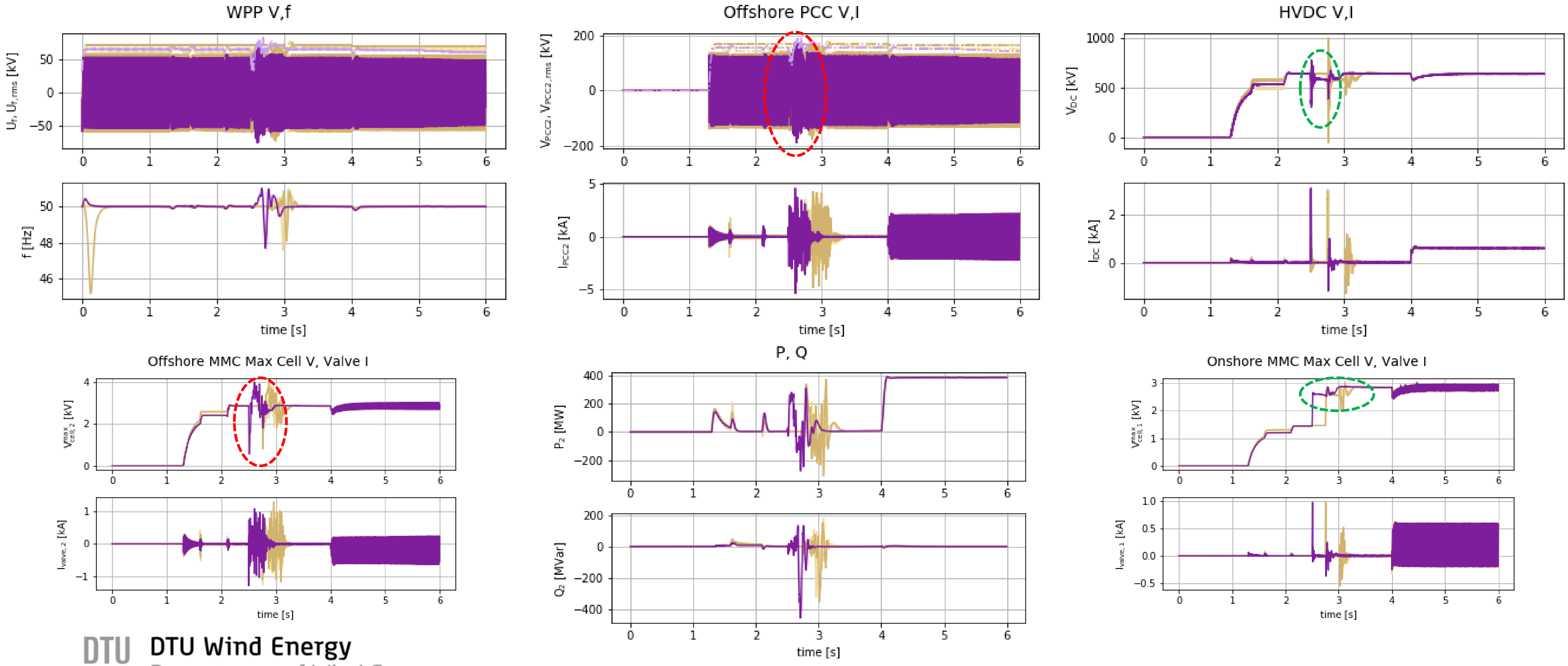
Comparison

1. Distributed PLL
2. VSG
3. DPC
4. PSC



Comparison

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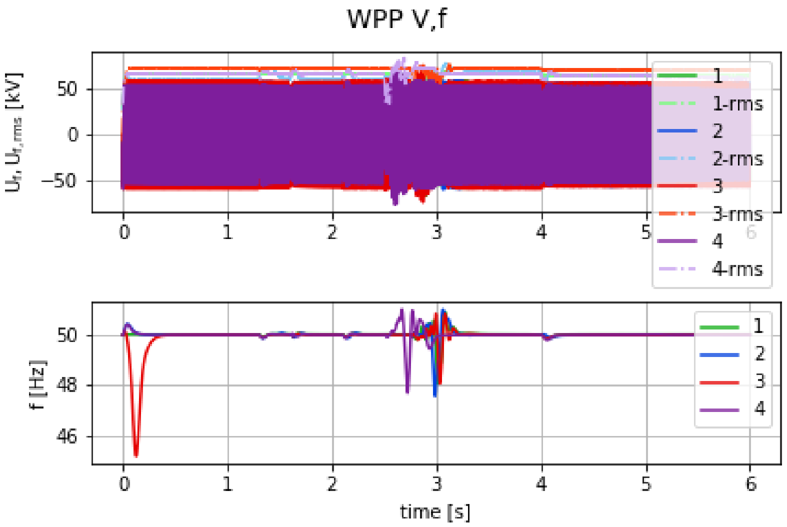
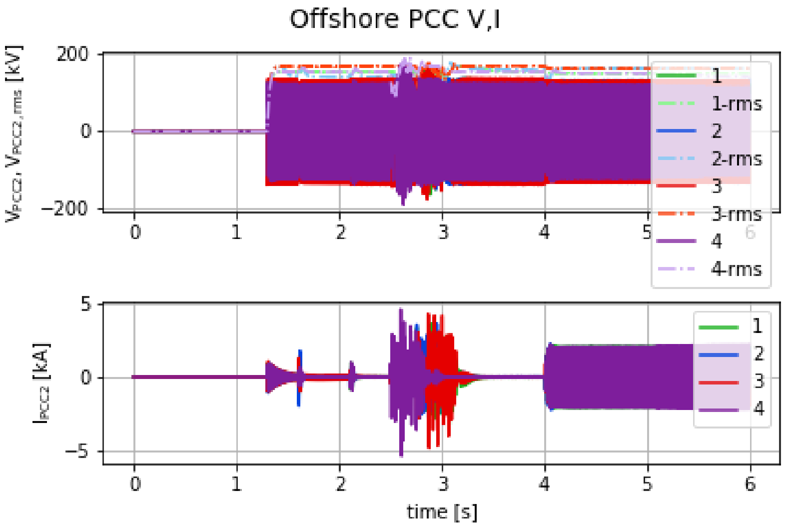
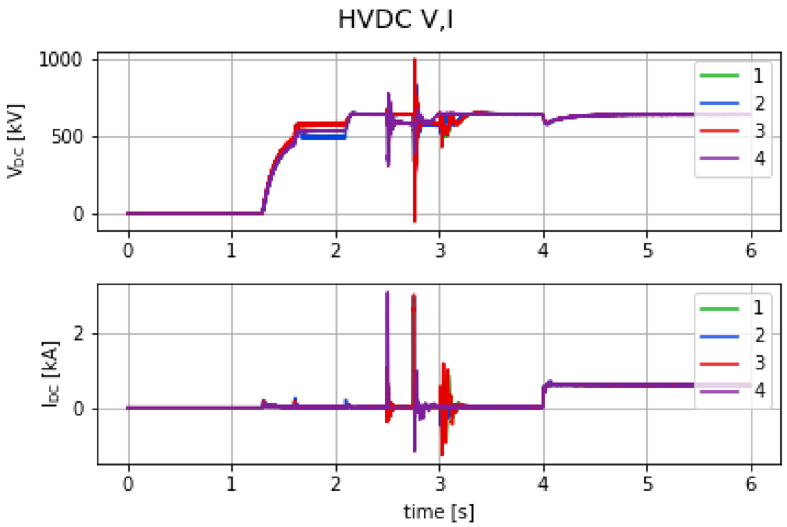
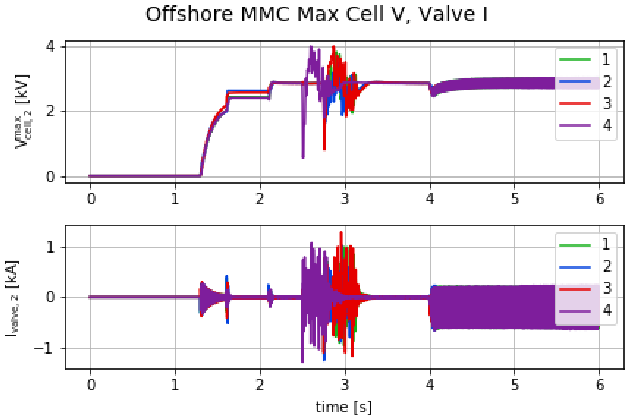
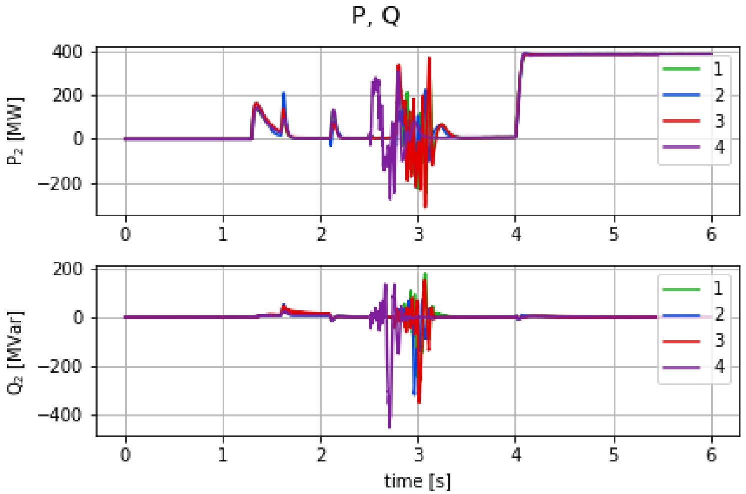
3. DPC
4. PSC

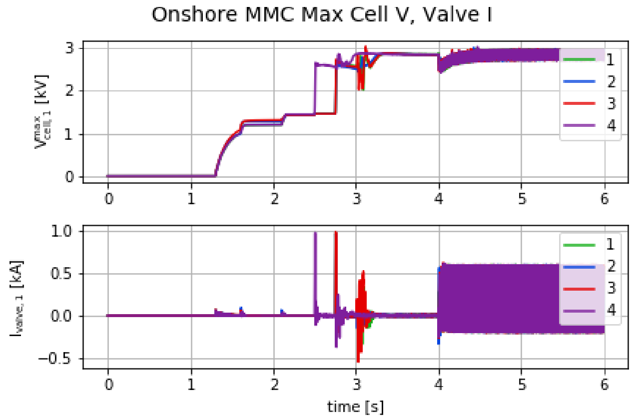






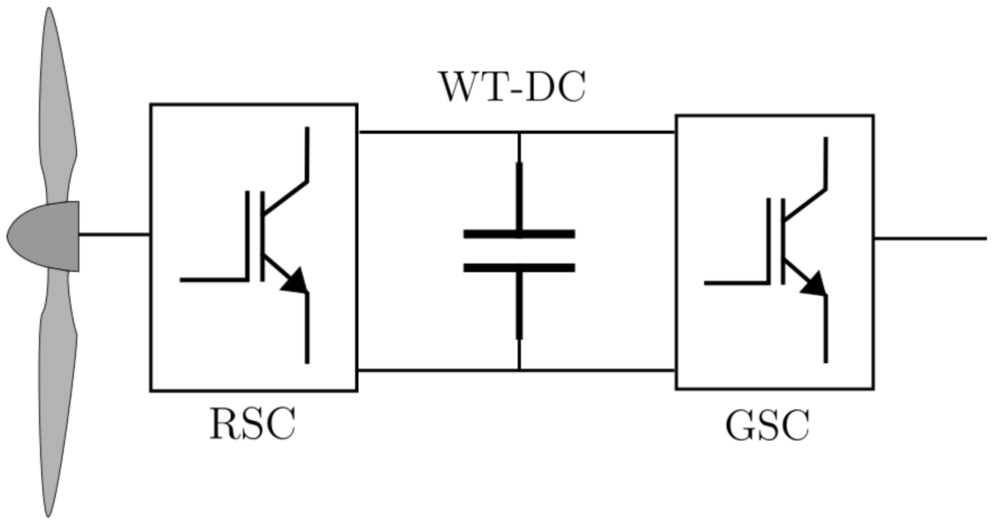






Next steps

- Details in model: *more stability issues.*
  - Converter switching:
    - GSC switching model instead of average model.
    - Add RSC – WTDC control [16]
  - Energization transients [17]:
    - WTTr magnetic inrush & saturation; currently WTTr: R+jX.
    - Array & Export cables *f*-model.
    - Dynamic V-issues: OV, harmonic distortions, switching surges
- BESS support
  - Facilitate BSR-TS1
  - Wind power uncertainty
  - Transients
- Offshore Islanding: substation load



Next steps

- Details in model: *more stability issues will arise.*
  - Converter switching:
    - GSC switching model instead of average model.
    - Add RSC – WTDC control [19]
  - Energization transients [10]:
    - WTTr magnetic inrush & saturation; currently WTTr: R+jX
    - Array & Export cables *f*-model.
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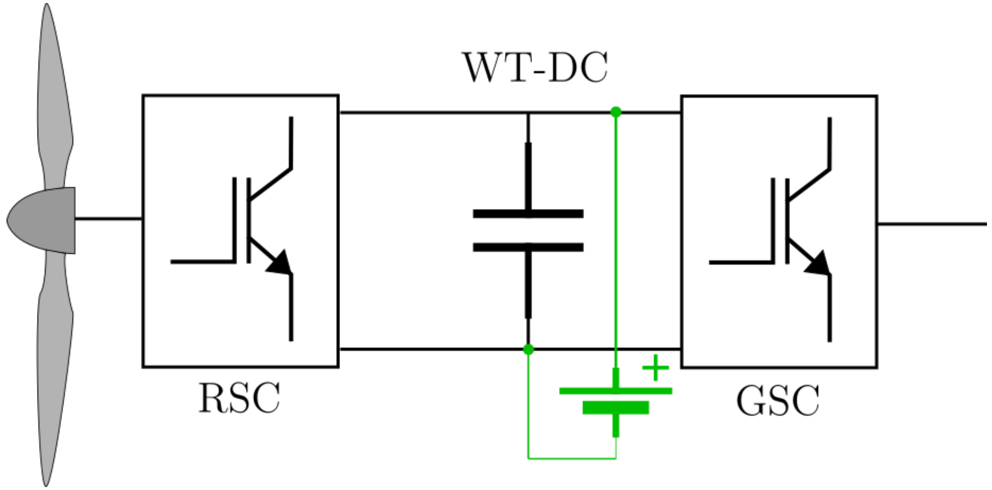

THANK YOU

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