Fast Harmonic compensation in hybrid HVDC offshore system

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❑ Outline

- Motivation
- HVDC Technology
- Hybrid HVDC system
- Harmonics compensation controller
- Conclusion and future work

Motivation

COP26 held in Glasgow in 2021

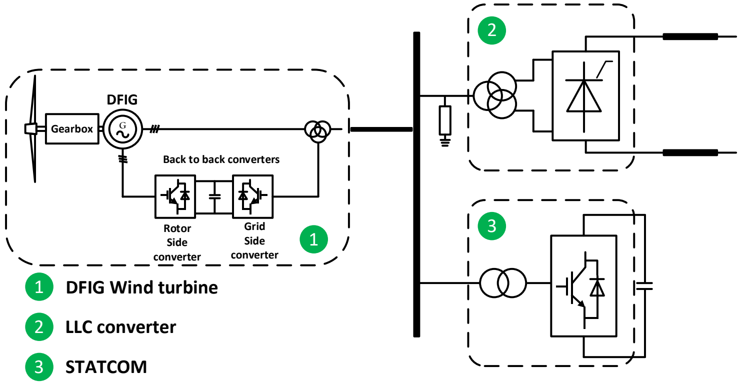
Many countries have proposed plans to reduce carbon emission

UK Government proposed a Zero Carbon 2050 Plan

Renewable energy plays an important role in power generation

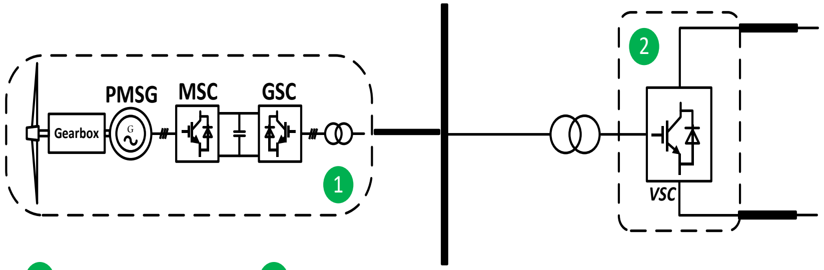
HVDC Technology

- LCC-HVDC



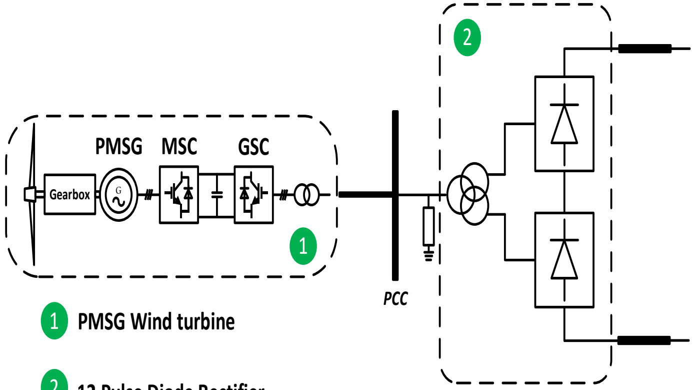
1 DFIG Wind turbine
2 LLC converter
3 STATCOM

- VSCC-HVDC



1 PMSG Wind turbine 2 VSC

- DR-HVDC



1 PMSG Wind turbine

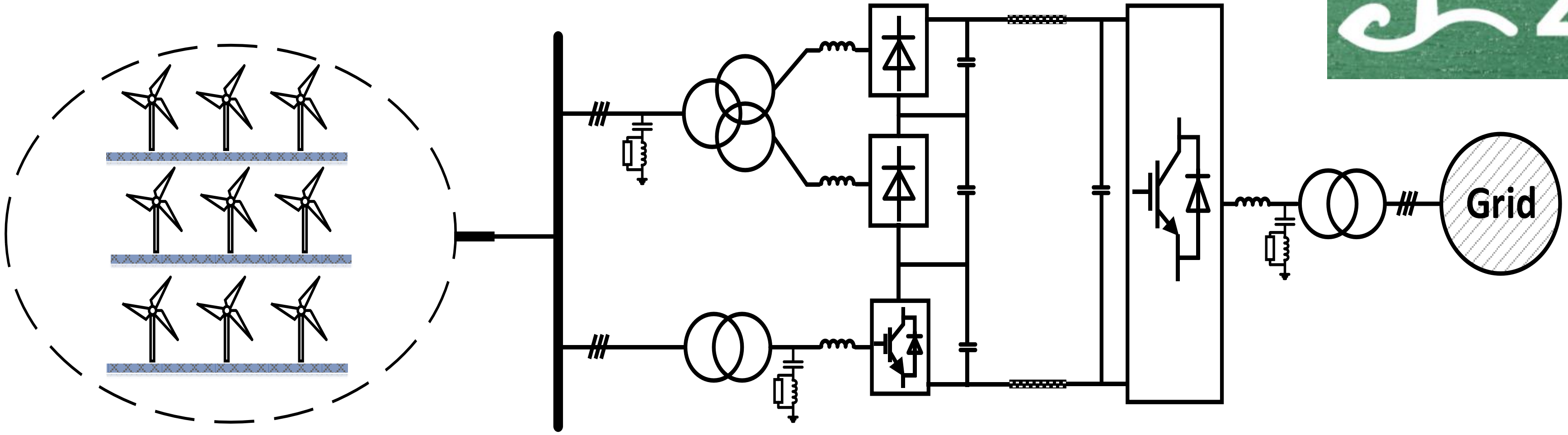
2 12 Pulse Diode Rectifier

✓ Large capacity
✓ High reliability
✓ Low power losses
✗ External voltage source for commutation
✗ Larger filters

✓ Ability to control ac voltage as Grid forming converter
✓ Fault current limit ability
✗ High switching losses
✗ Filter required

✓ Low cost
✓ High reliability
✓ Low power losses
✗ Uncontrollable
✗ Larger Filter required
✗ Need WTs converter as Grid forming converter

❑ Hybrid HVDC system



Hybrid converter components:

12 pulse diode rectifier (12P-DR)： uncontrollable power electronics device

2 level VSC/MMC: DC voltage controller and ac voltage controller

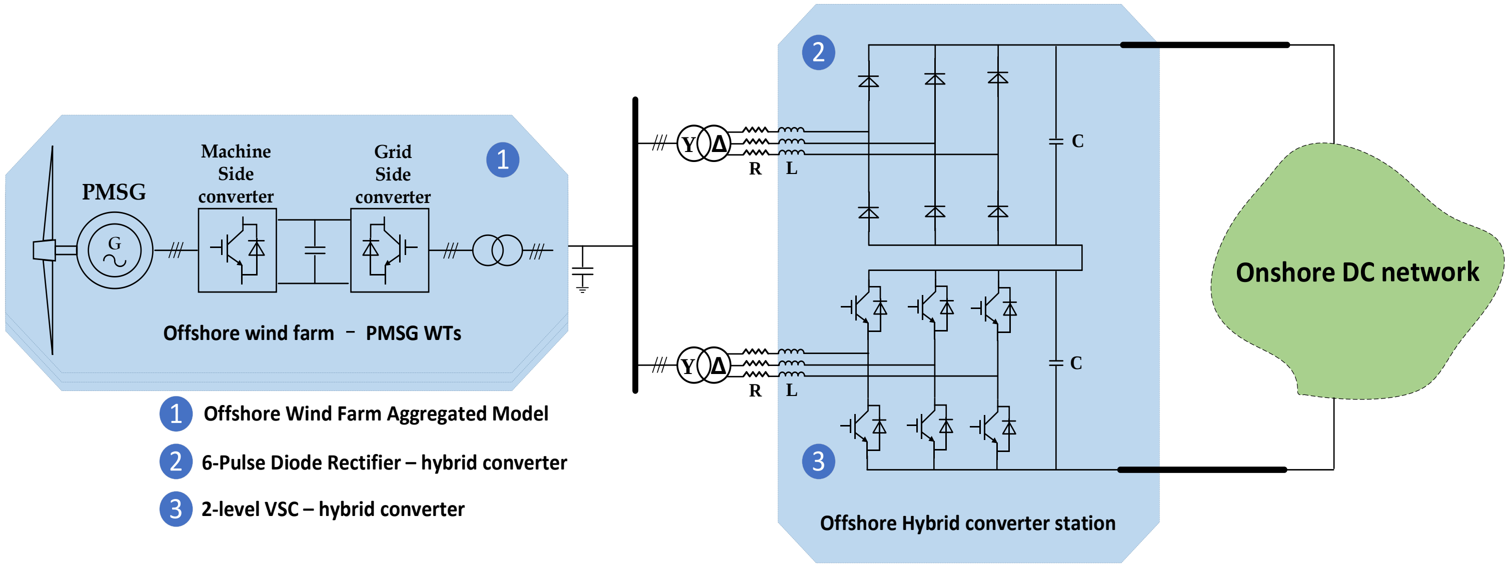
VSC functions as active power filter to cancel the harmonics current produced by 12P-DR

Advantages:

- increase power capacity
- low cost and small footprint
- change power exchange between AC and DC side by control VSC DC voltage

Disadvantages:

- no current loop control
- complex transformer connection
- footprint and maintenance not discuss in detail

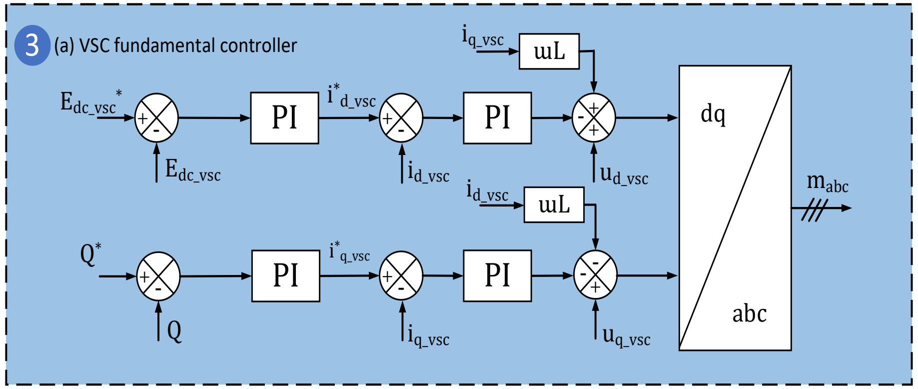


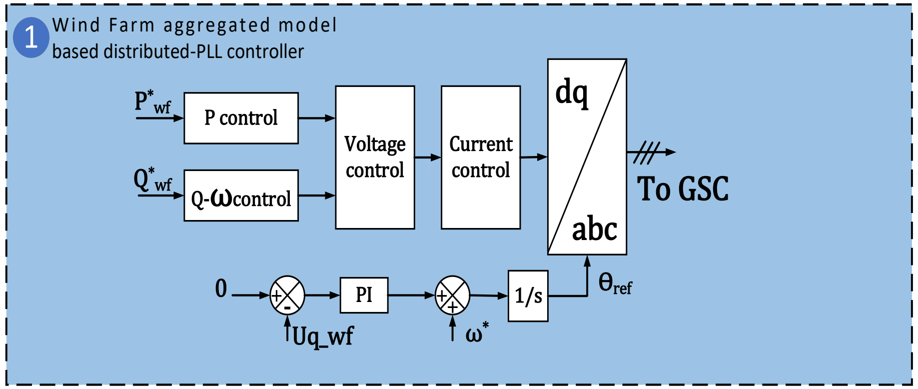
Offshore hybrid converter station:
2 Level VSC converter and 6P-DR in series connection

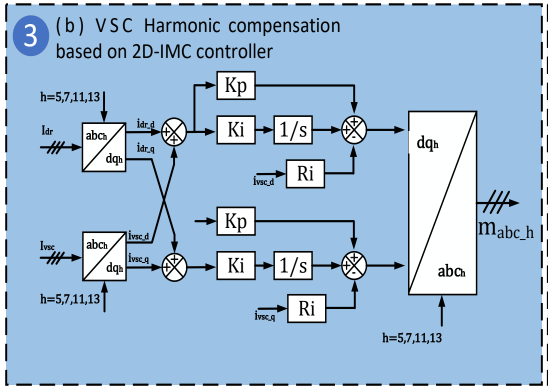
- Simply transformer structure

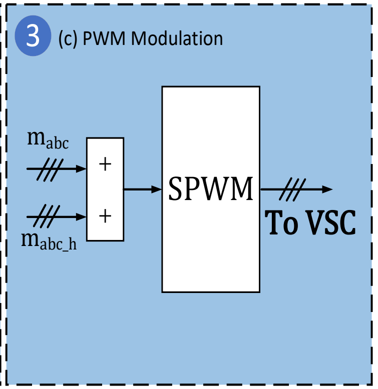
Improved control system

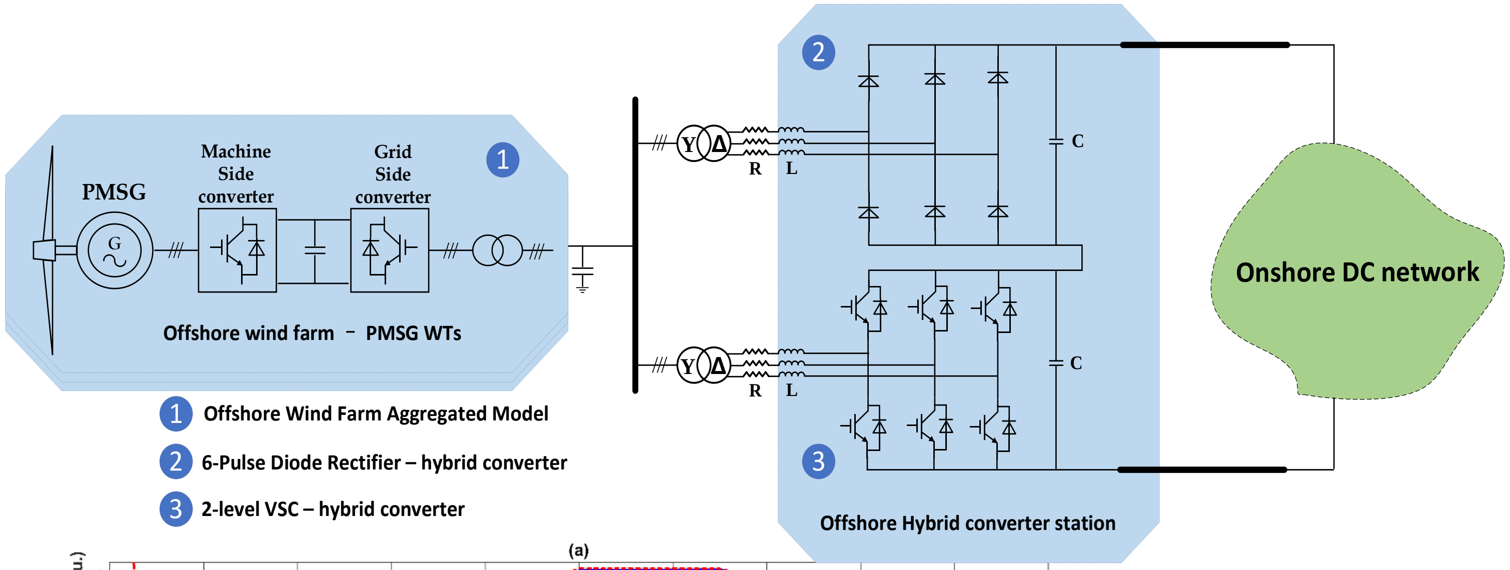
Harmonics compensation using Serval Reference Frame(SRF) technique

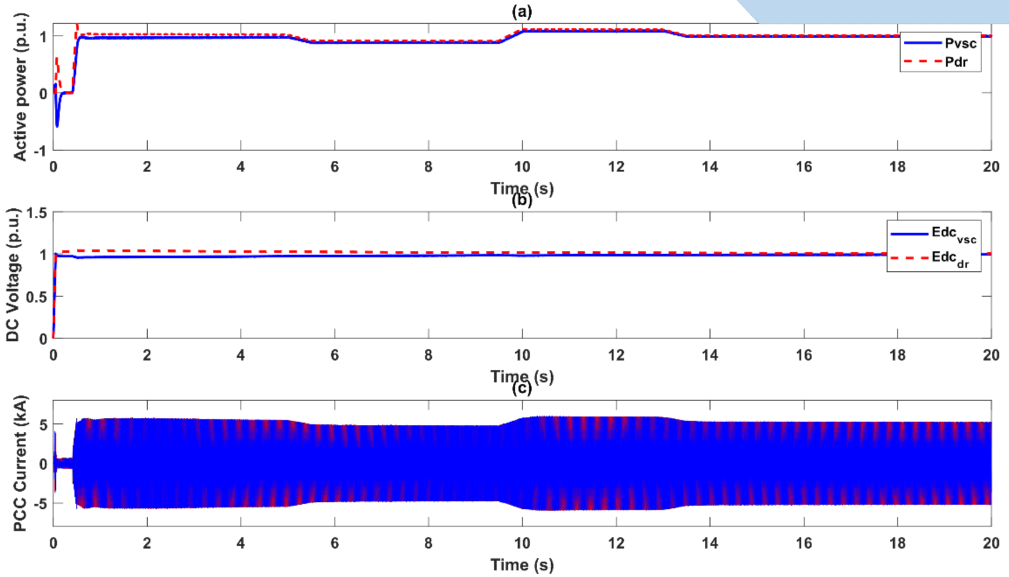


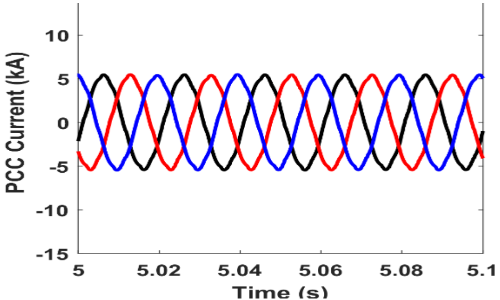


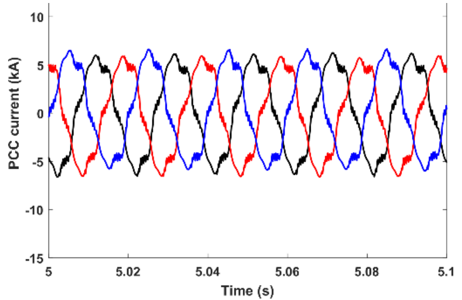












- The simulation runs at different wind farm power levels to test the hybrid HVDC performance

- Figure (a) and (b) shows the active power and dc voltage of hybrid converter components. Transmitted power is proportional to its dc voltage

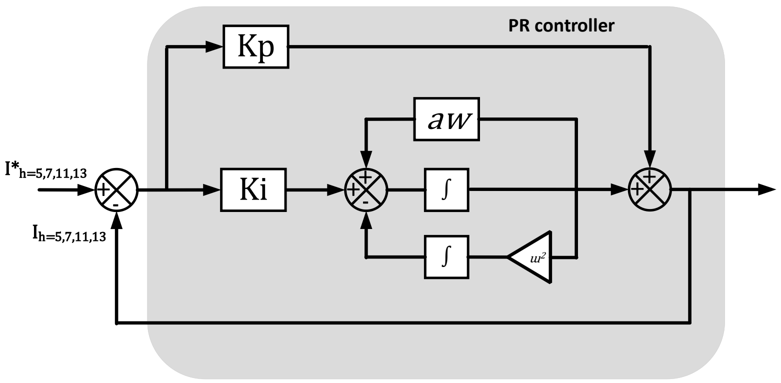
- For comparison

  The PCC current with harmonics compensation controller (Right figure)

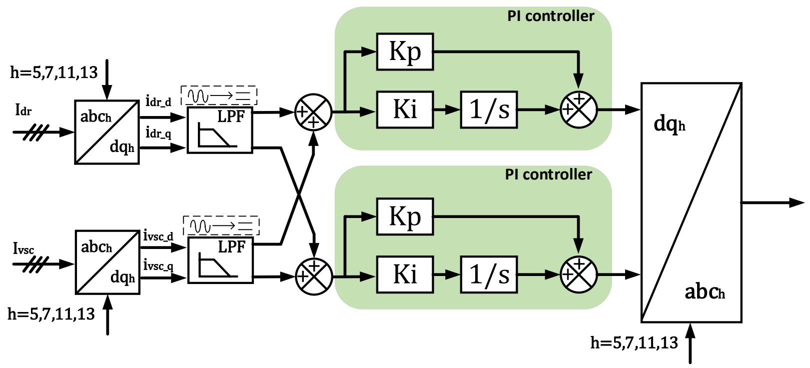
  The PCC current without harmonics compensation controller (left figure)

❑ Harmonics compensation using different controller

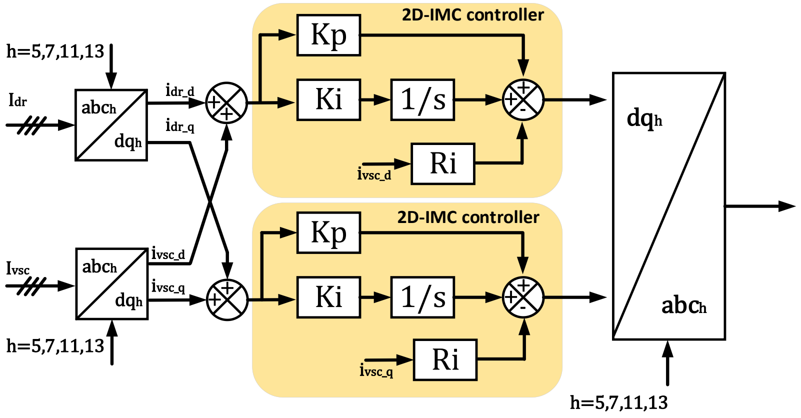
- Proportional Resonant(PR)controller



- PI controller



- 2DF-IMC controller



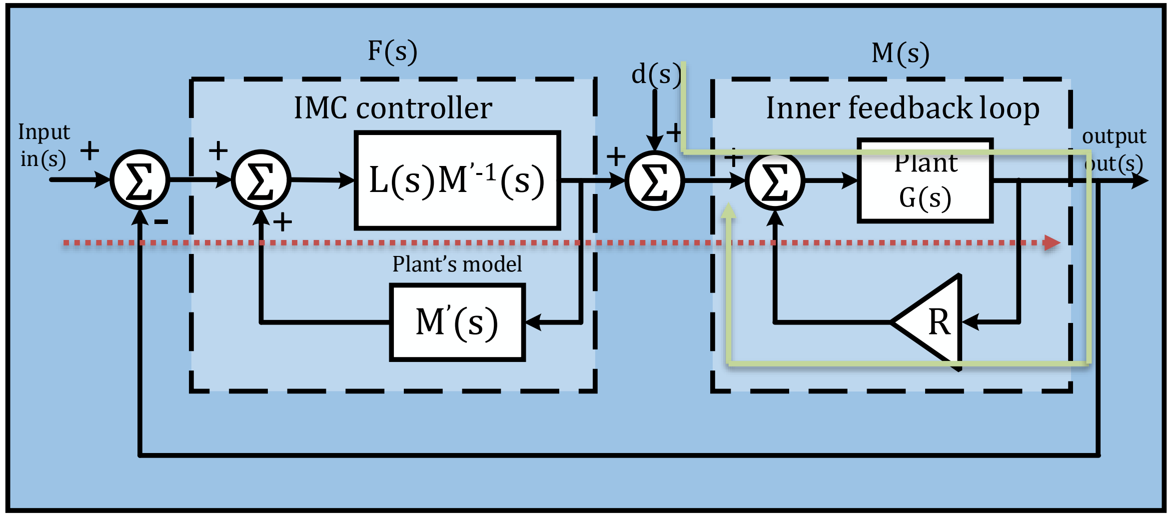
- ➢ By introducing an infinite gain at the desired resonant frequency
- ✓ Fast response for set-point changes
- × Complex tuning process
- × Easy influenced by Grid frequency variations resonant frequency will be tuned to reference frequency, infinite band is narrow

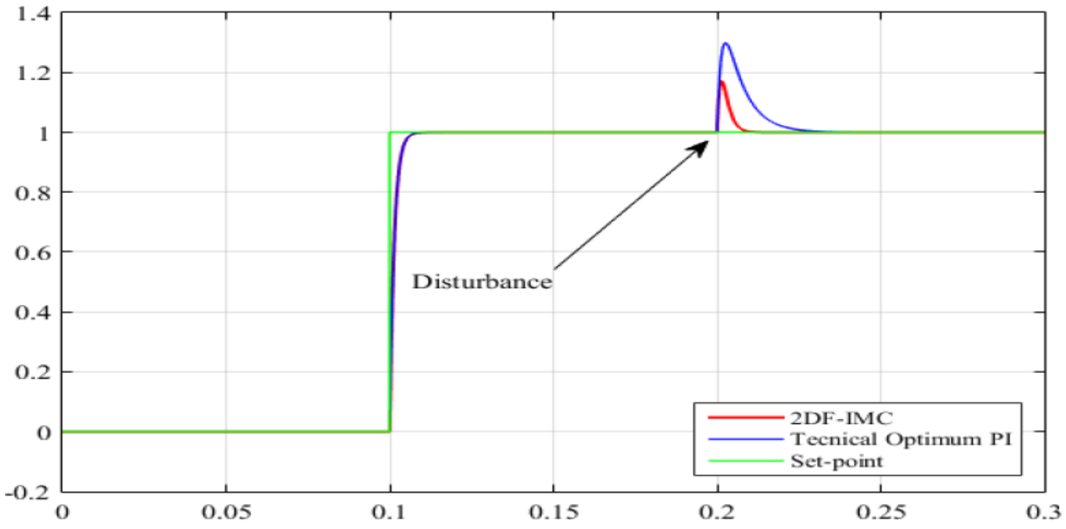
- ➢ Applied several synchronous dq harmonic frame to detect the harmonic current, then filter by low pass filter to get dc signal, finally tuning by PI controller
- ✓ Individual harmonics current controlled by dc signal
- ✓ Easy to tune
- × Slow response to set point – the delay of Low pass filter in SRF technique.

- ➢ Using two degrees of freedom internal model controller in SRF technique
- ➢ Remove the low pass filter to provide fast response to set point
- ➢ Harmonics component controlled by ac signals

❑ Harmonics compensation using different controller

- IMC controller





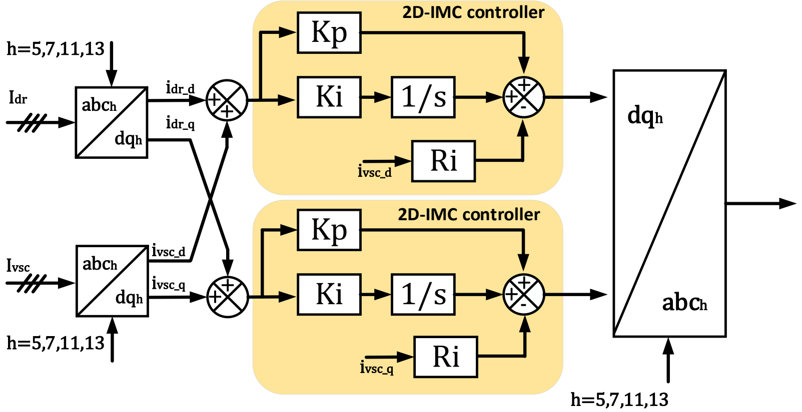
- ➢ The Internal Model Controller (IMC) technique relies on the internal model principle
- ➢ The philosophy: control action over a plant can be achieved only if the control system includes, either implicitly or explicitly, some representation of the process to be controlled

In harmonics compensation control loop

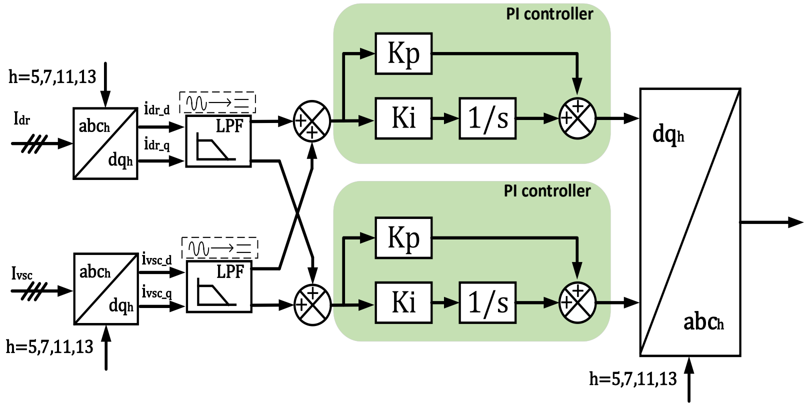
Which components are the disturbance?

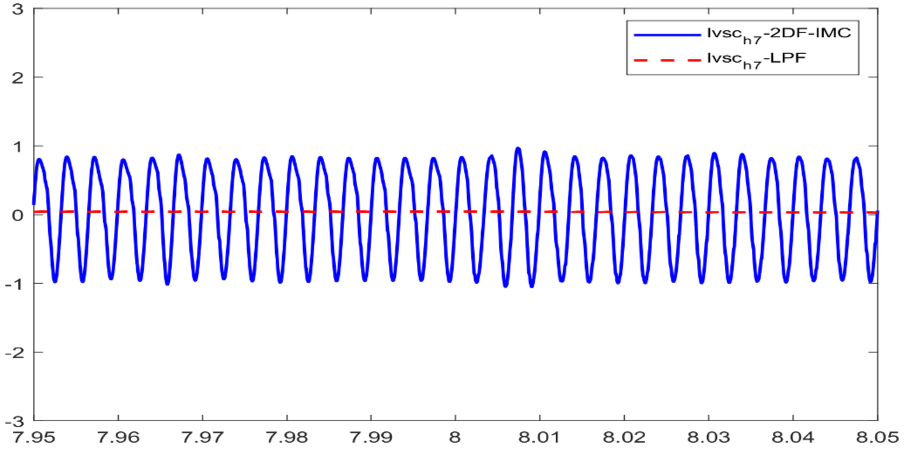
- Harmonics compensation controller using 2DF-IMC

➢ 2DF-IMC controller



➢ PI controller





The sequence of the n harmonics and the sequence of the rest of harmonics:

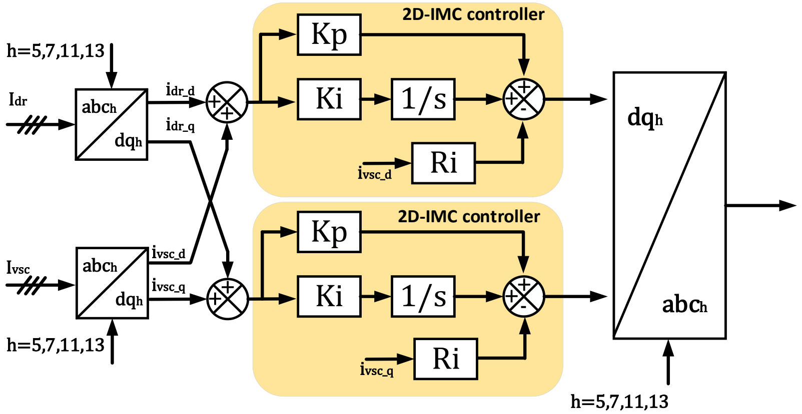
$$i_{n\_d} = \Gamma_n i_n \cos(\beta_n) + \sum_{k=1,k\neq n}^{\infty} \Gamma_k i_k \cos(-\Gamma_k[\Gamma_n n - \Gamma_k k](\omega_s t) + \beta_k)$$

$$i_{n\_q} = i_n \sin(\beta_n) + \sum_{k=1,k\neq n}^{\infty} i_k \sin(-\Gamma_k[\Gamma_n n - \Gamma_k k](\omega_s t) + \beta_k)$$

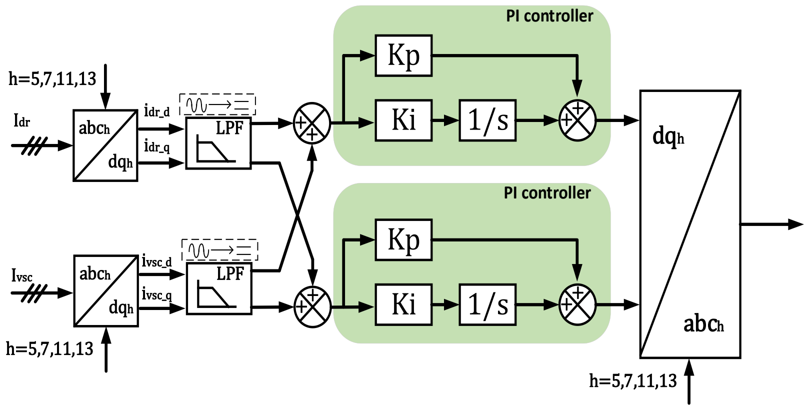
dc component   ac component

- Harmonics compensation controller using 2DF-IMC

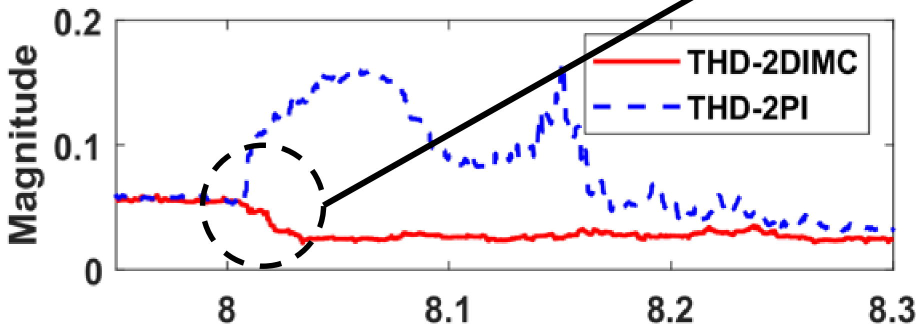
➢ 2DF-IMC controller



➢ PI controller



Cancellation time: 20ms



Total harmonic distortion (THD) of phase current

❑ Conclusion and future work

Conclusion

- Hybrid converter based on 6P-DR and VSC used for offshore HVDC system
- Low cost, simple structure in offshore converter station
- Using 2DF-IMC controller replace PI controller in harmonics compensation control loop

Future work

- Exploring the size of hybrid converter components (diode rectifier, VSC converter)
- Hardware

Many thanks!

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