NTNU
Norwegian University of Science and Technology

HVDC-connection of Large Offshore Wind Farms Using a Low-Cost Hybrid Converter

Inga Haukaas, Raymundo E. Torres-Olguin, Olimpo Anaya-Lara

DeepWind'2017, Trondheim

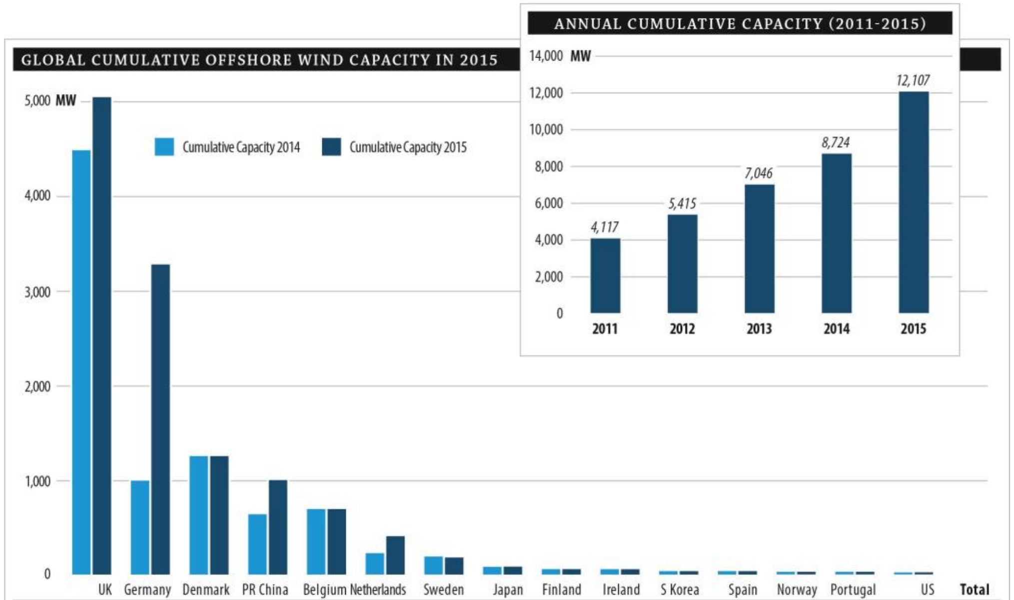
Outline

1. Introduction
2. New hybrid solution
3. System description
4. Control objectives
5. Control system
6. Simulation
7. Conclusion

Introduction

- Offshore wind capacity: 3% of global installed capacity.

- More than 90% installed in the north of Europe.



	UK	Germany	Denmark	PR China	Belgium	Netherlands	Sweden	Japan	Finland	Ireland	S Korea	Spain	Norway	Portugal	US	**Total**
Total 2014	4,500.4	1,012	1,271	654	712	247	212	50	26	25	5	5	2	2	0.02	**8,724**
New 2015	572.1	2,282.4	0	360.5	0	180	0	3	0	0	0	0	0	0	0	**3,398**
Total 2015	5,066.5	3,294.6	1,271.3	1,014.7	712.2	426.8	201.7	53	26.3	25.2	5	5	2.3	2	0.02	**12,107**

Source: GWEC, 2016

Introduction – Offshore wind farms

- Key benefits:
  - great wind resource
  - vast space
  - reduced visual noise and impact
- Challenge:
  - installation of big platforms
  - power transmission over long distances
- Ultimate goal: reduce cost.

Source: BorWin1, ABB

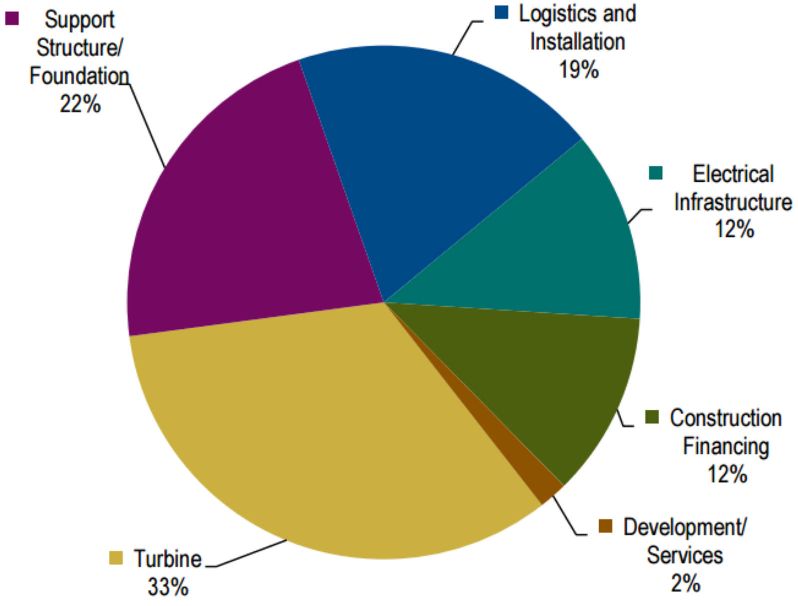
- Study by Ernst & Young (EY) in 2015:
  - promising results for long term development
  - One key priority: ensure cost-effective grid investments and connections
- HVDC most efficient for long sub-sea cables.
  - Need a converter station!

Introduction – Converter platform

- Challenge:
  - Reduce cost of converter platform.
- Solution:
  - Reduce size of platform and use less expensive and more robust power devices.

- A VSC station is smaller than a LCC station.
- Disadvantage of the VSC:
  - large switching losses and expensive power devices.
  - Reduce losses and cost by introducing a hybrid converter.

<u>Cost of OWF:</u>



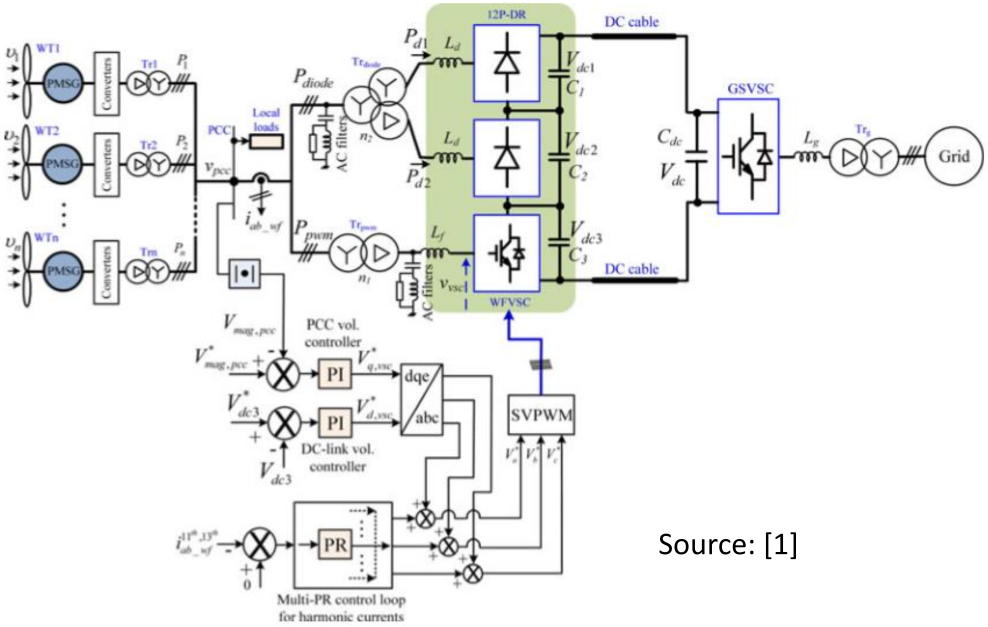
Navigant Consulting, 2013

New hybrid solution

- 12-pulse diode rectifier (DR) connected in series with a VSC.
- Anticipated results: (From ref: [1])
  - efficiency = 99.07% (VSC: 98.4%)
  - cost of power devices = 53.47% of VSC
  - same size as HVDC light station
- YYD - Transformer:
  - Eliminate 5th and 7th order harmonic current component.

- Takes advantage of both DR and VSC technology.
  - VSC: smaller filter banks
  - DR: higher efficiency

- More robust
  - less switching devices.

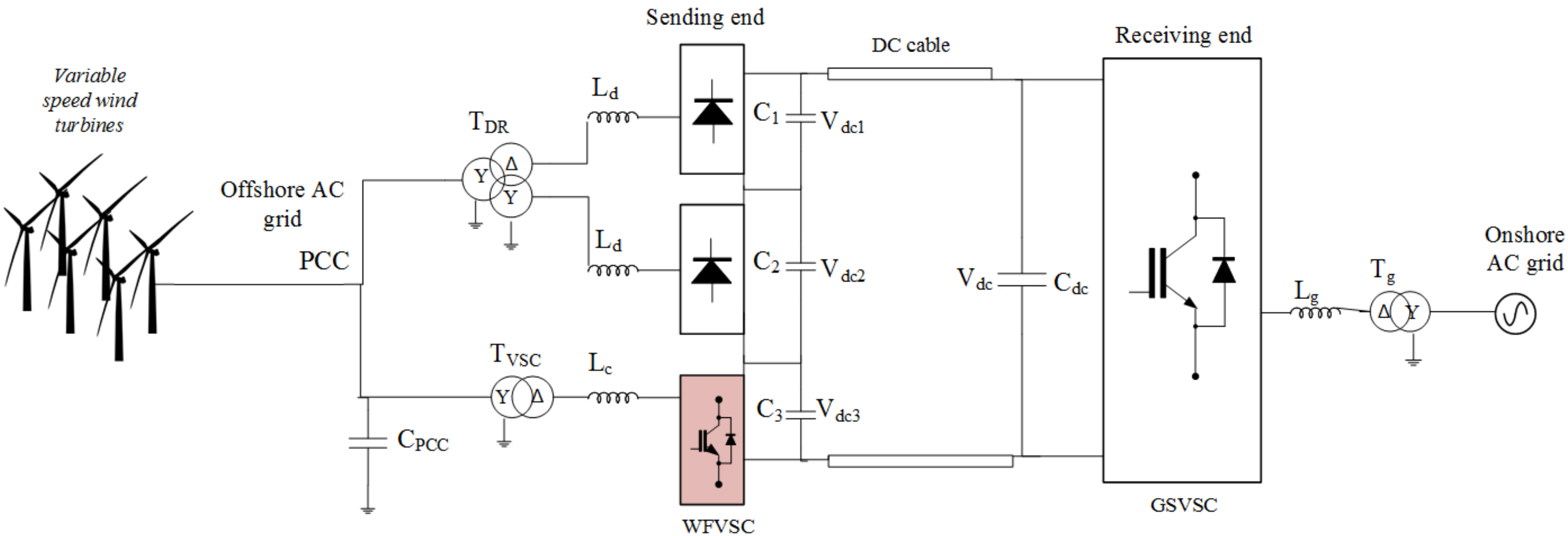


Source: [1]

System description

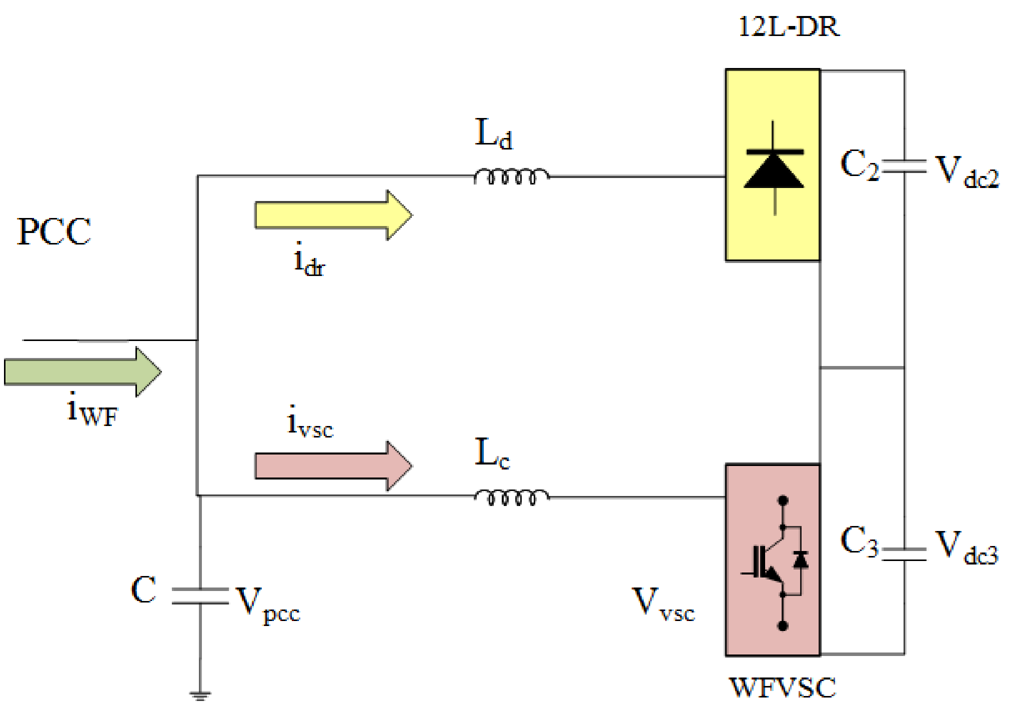
- BorWin1, reference project
- Simplified wind farm
- Control of the WFVSC is the focus of this paper

Power and Voltage	Parameters	Values
Base values	Power rating [MW]	400
	DC Voltage [kV]	±150
Filter values	C_{PCC} [μF]	6.0
	$C_{1,2,3}$ [μF]	300
	C_{dc} [μF]	70
	L_d [mH]	46
	L_c [mH]	35
	L_g [mH]	28
Transformers	T_{DR} [kV]	33/76/76; 0.1 p.u.
	T_{VSC} [kV]	33/67; 0.1 p.u.
	T_g [kV]	170/300; 0.1 p.u.



Control objective

1. Voltage tracking control $V_{pcc} \longrightarrow V_{pcc}^*$ (m,f)
2. Balancing control $V_{dc3} \longrightarrow V_{dc3}^*$
3. Harmonic control $i_{WF} \longrightarrow i_{WF}^* = gV_{pcc}$

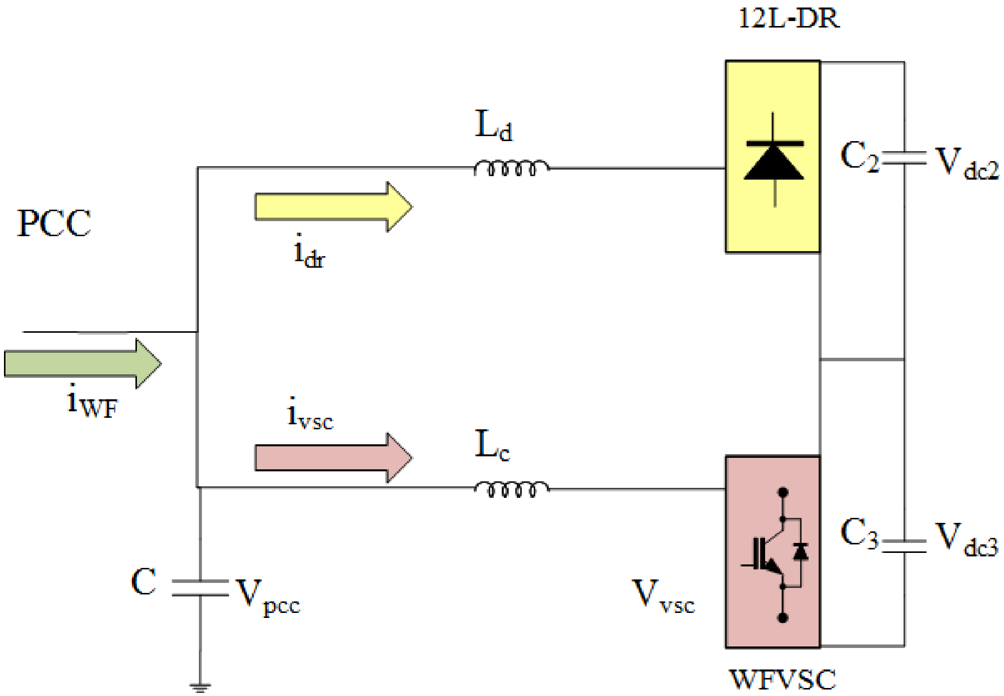


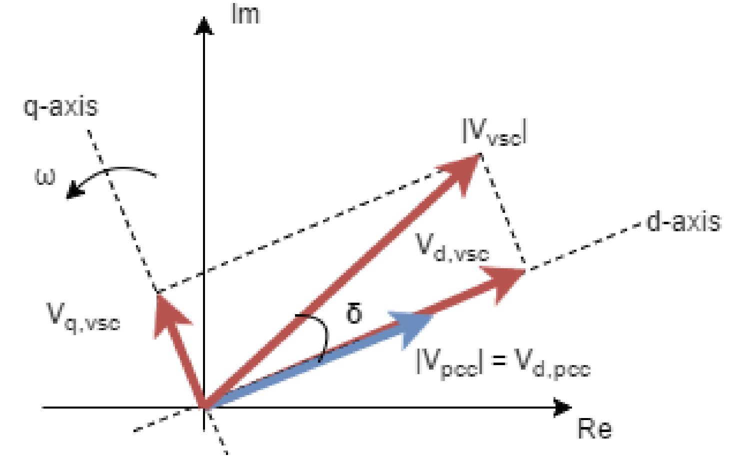
Control objective 1 & 2

1. Voltage tracking control $V_{pcc} \longrightarrow V_{pcc}^*$ (m,f)
2. Balancing control $V_{dc3} \longrightarrow V_{dc3}^*$

$$P = \frac{|V_{VSC}|\sin\delta}{\omega L_C} \cdot |V_{PCC}| \longrightarrow P = \frac{V_{q,VSC}}{\omega L_C} \cdot |V_{PCC}|$$

$$Q = \frac{|V_{VSC}|\cos\delta - |V_{PCC}|}{\omega L_C} \cdot |V_{PCC}| \longrightarrow Q = \frac{V_{d,VSC} - |V_{PCC}|}{\omega L_C} \cdot |V_{PCC}|$$

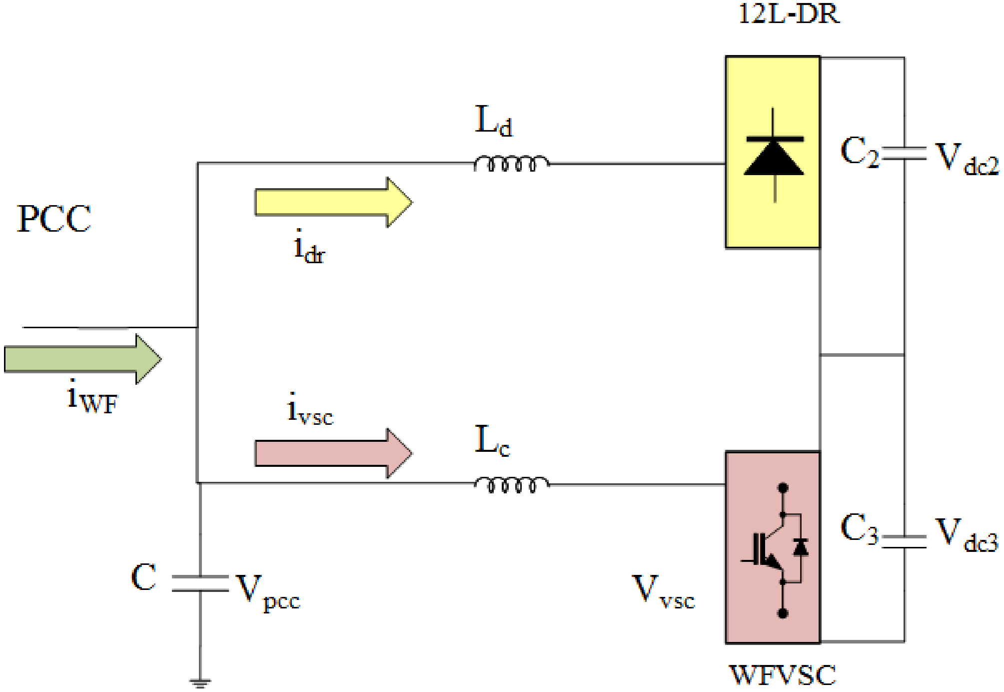




Control objective 3

Harmonic control $i_{WF} \longrightarrow i_{WF}^* = gV_{pcc}$

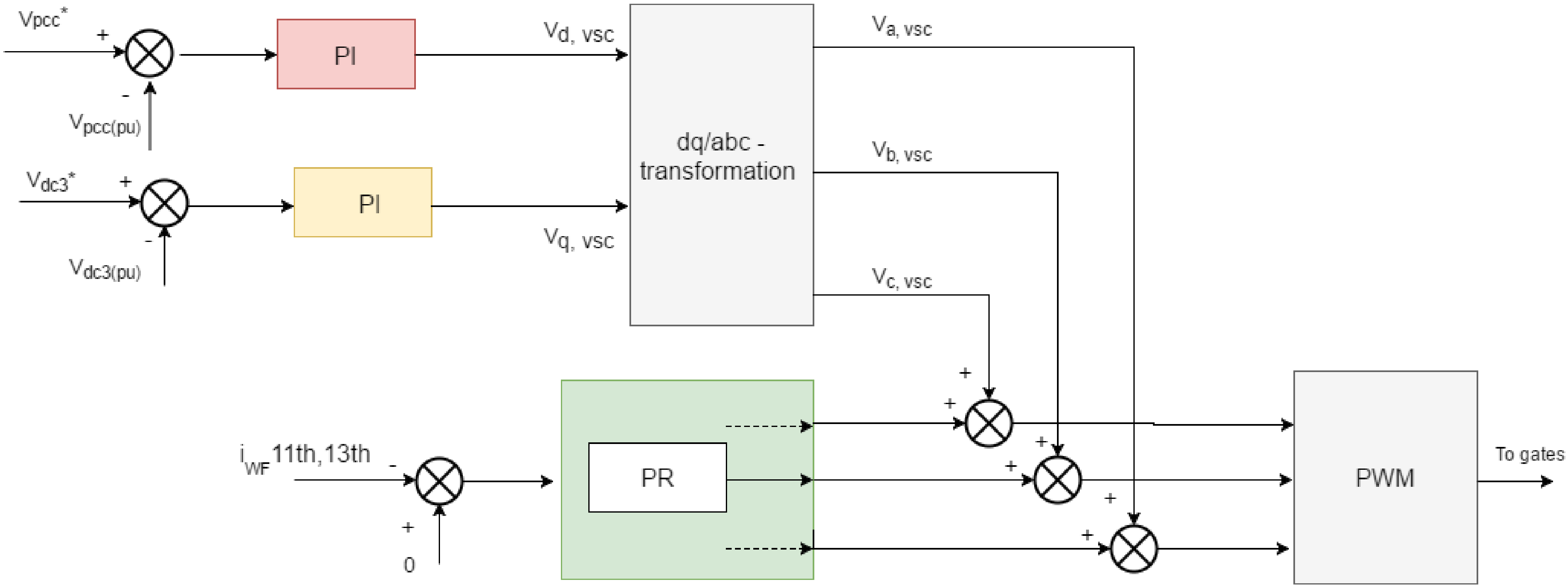
WFVSC works as an active filter by utilizing a proportional-resonant (PR) filter.



Transfer function for the integrator term of the PR controller:

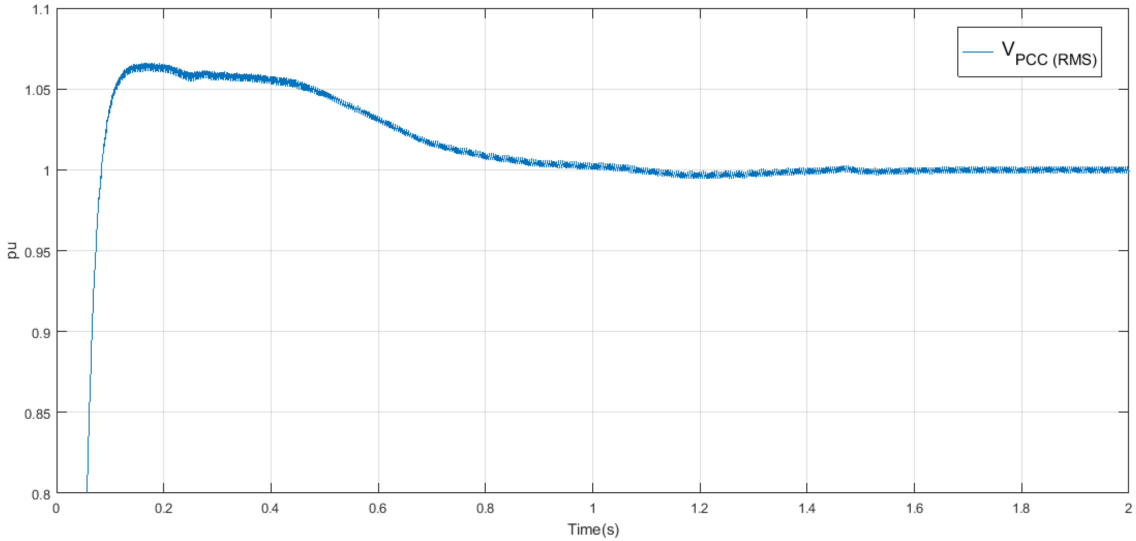
$$G_{I_h}(s) = \sum_{h=11,13} K_{I_h} \frac{s}{s^2 + (\omega \cdot h)^2}$$

Control system



Simulation

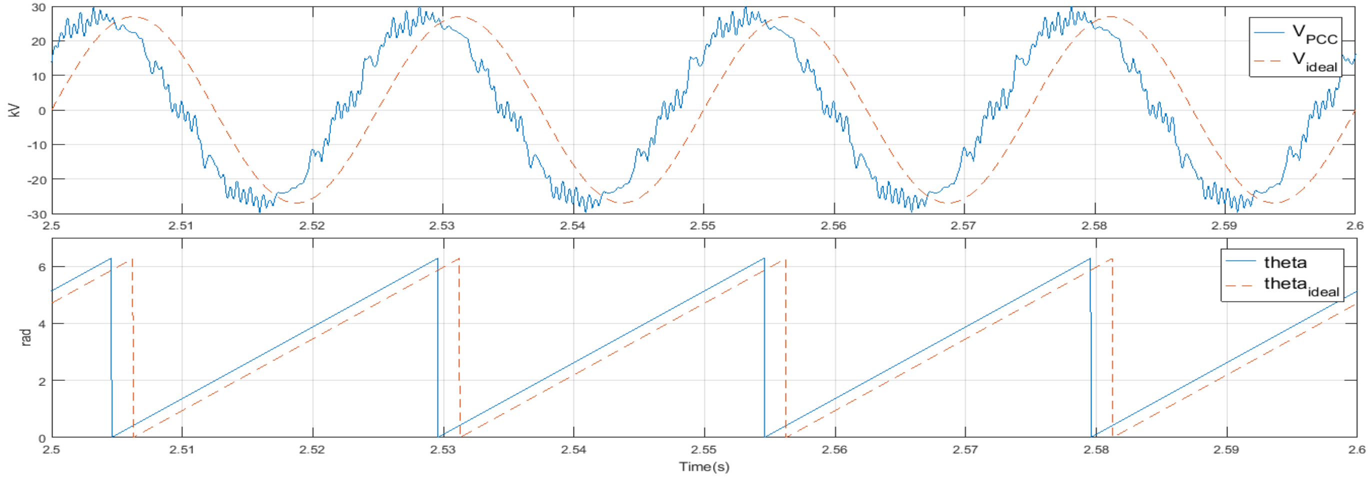
- Control objective 1: Voltage tracking control



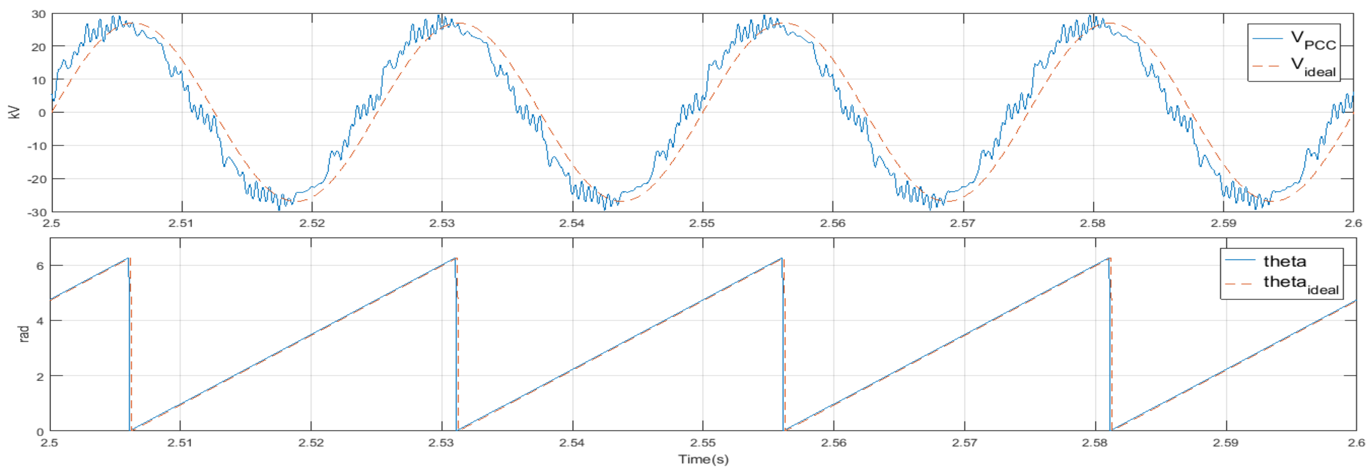
- Control objective 2: Balancing control
  - Preliminary implementation: used an ideal voltage source where Vdc3 = Vdc/3

Simulation

- Control objective 3: Harmonic control



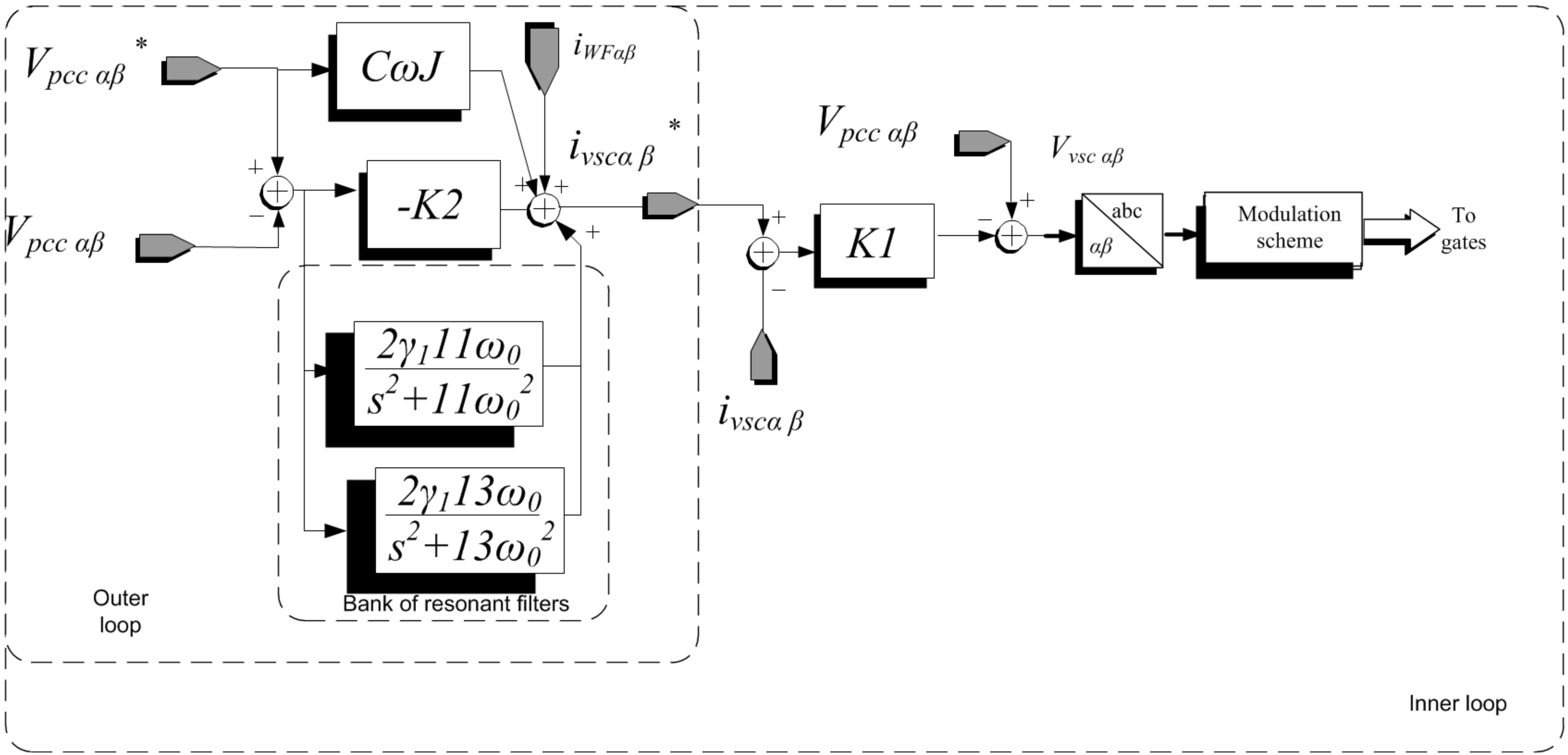
Unfiltered



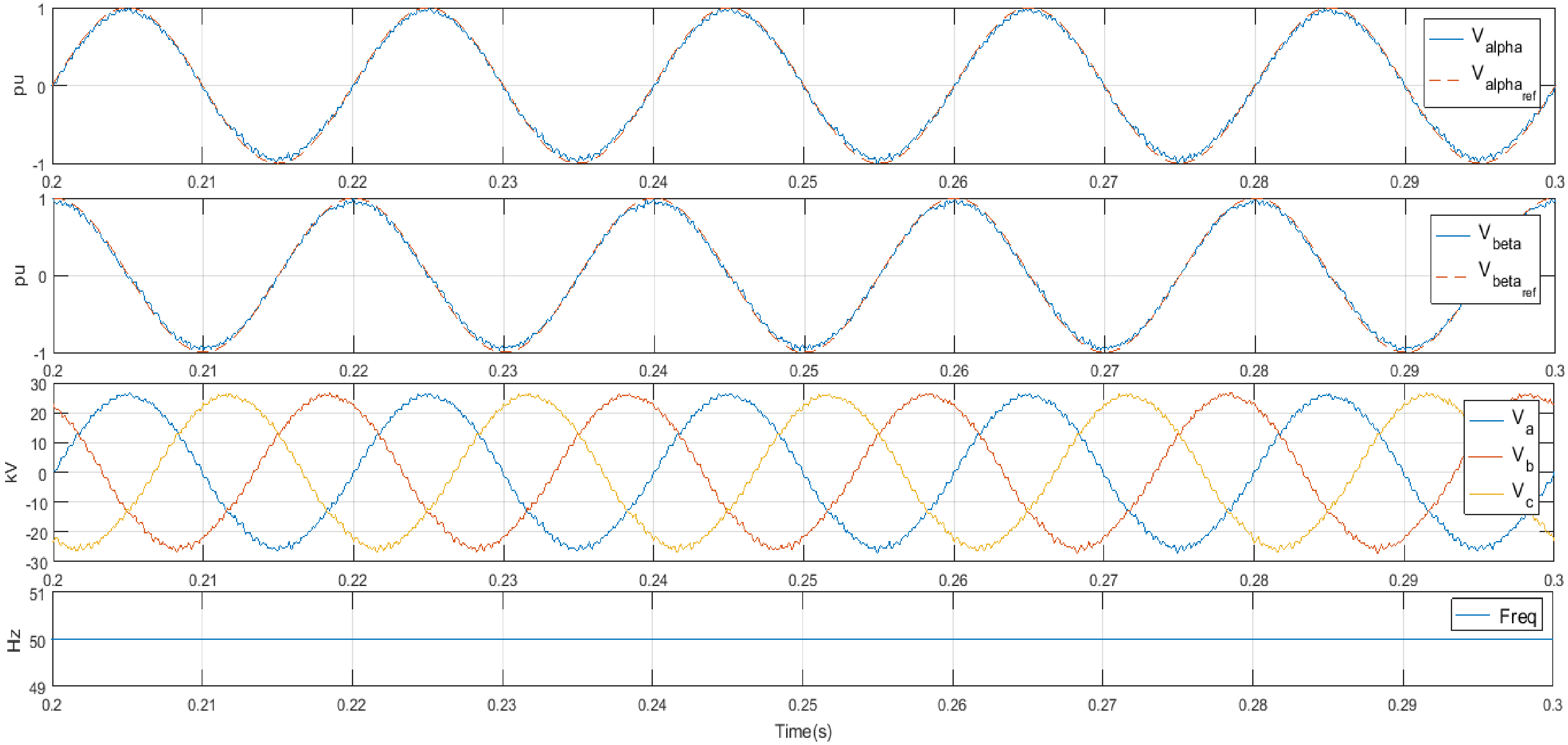
Filtered

Alternative controller

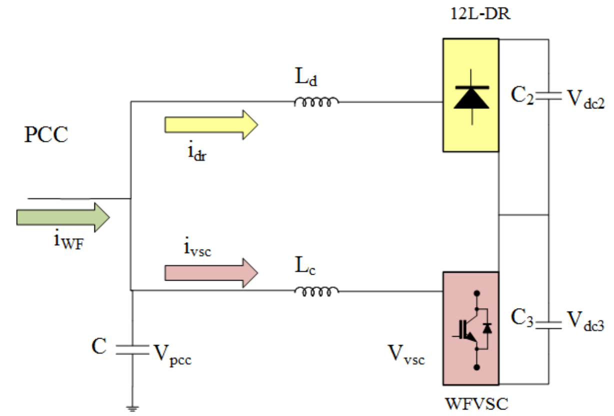
Model-based controller in stationary reference frame:



Preliminary results



Conclusion



- Challenging controller!
- Reduced number of switching devices
  - More robust
  - Lower switching losses > Higher efficiency
  - Reduced cost of power devices

- Reduced size of filter banks compared with the DR

Reduced cost of offshore converter station

Future work: ancillary services

Thank you!

Questions?

[1] T. H. Nguyen, D. C. Lee, and Chan-Ki Kim. “A Series-Connected Topology of a Diode Rectifier and a Voltage-Source Converter for an HVDC Transmission System”. In: *Power Electronics, IEEE Transactions on* 29.4 (2014), pp.1579–1584