AC Network Support using large offshore wind farms connected through MTDC systems

by
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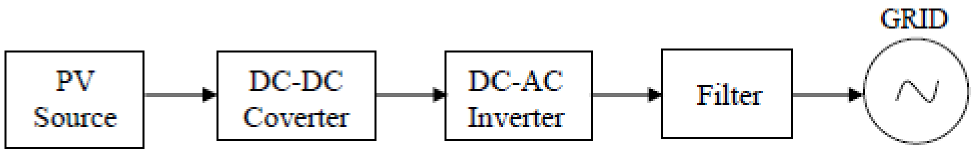
Outline

- Professional background
- Project objective
- Ancillary services in power system
- Power system balancing with wind power
- Ancillary services from VSC-HVDC connected offshore WPPs
- Project schedule

MEDOW
MULTI-TERMINAL DC GRID FOR OFFSHORE WIND

Professional background

- Master of Technology (Power &Control) – Indian Institute of Technology, Kanpur, India (2009)
- Master thesis at TU Berlin, Germany- Modeling and Control of Grid Connected Photovoltaic system using PSCAD/EMTDC



- Senior Executive (Design & Development) at High Voltage Instrument Transformer Division, Crompton Greaves Ltd, India (2009-2011)
- Worked for Grid Systems R &D, ABB GISL, Chennai, India - Main Circuit Design, Transient Simulations – VSC HVDC (2011-2014)
- Enrolled for PhD at DTU Wind Energy on 15th March 2014

Project objective

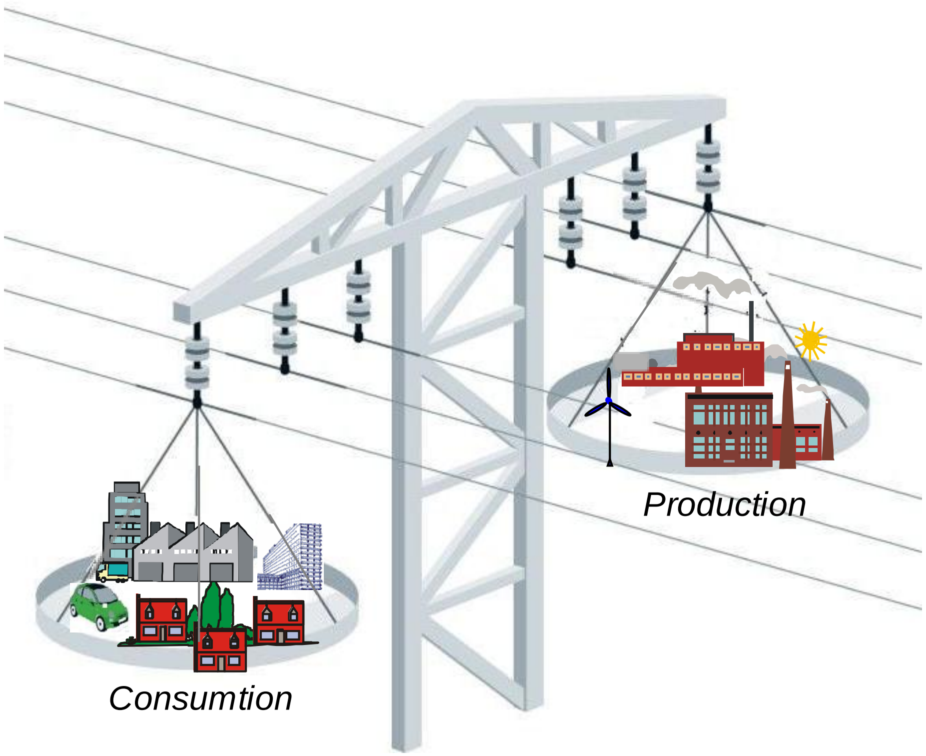
- To develop, implement, and test coordinated control strategies for ancillary services from large offshore wind power plants connected in HVDC grid.
- Investigate the technical capabilities and control characteristics of large offshore wind farms connected to HVDC grid.
- Develop control strategies that will allow the effective delivery of ancillary services from HVDC grids with large amounts of wind power

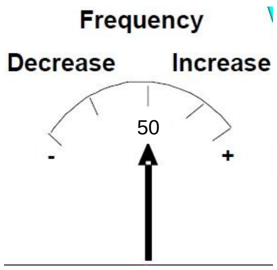
Ancillary services in power system

- **Ancillary Services** are support services in the power system, particularly those which are necessary to support the transmission capacity and are essential in maintaining power quality, reliability and security of the grid.

- **Active power control:** frequency regulation, ramping schedules, energy imbalance.
- **Reactive power control:** voltage regulation, capacitor switching and generator scheduling.

Power balance in power system





Balance measurable through frequency !

Frequency is global indicator of consumption-production balance !

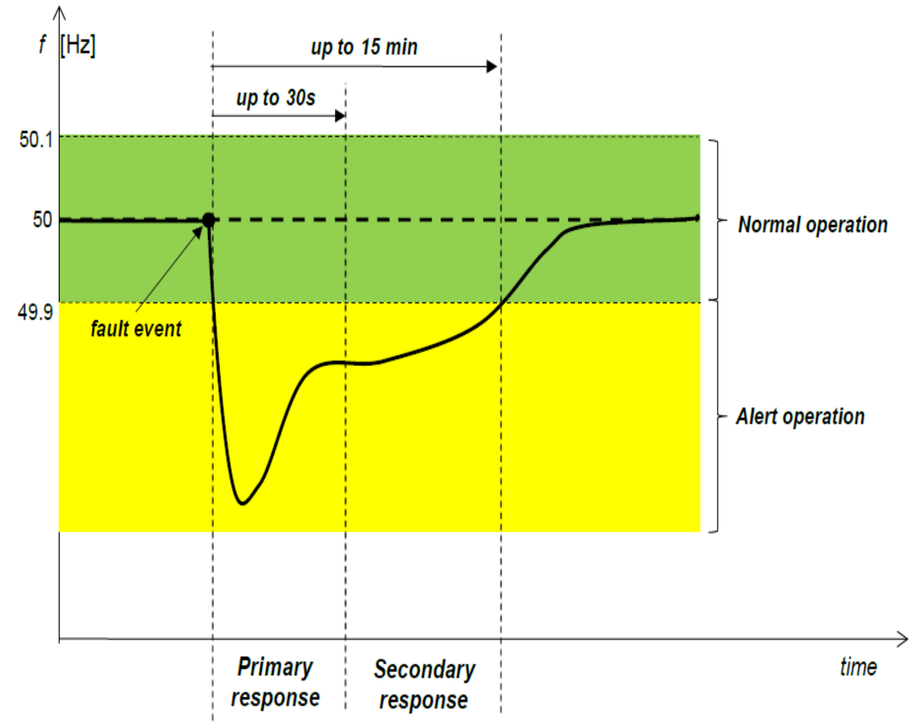
Frequency regulation in power system

Rate of frequency decay depends on power system inertia provided by synchronous geneators.

Primary Control: Through frequency droop control – speed governors action- within 30 seconds.

Secondary Control: Acts within 15 minutes. Redistributes load among generating units.

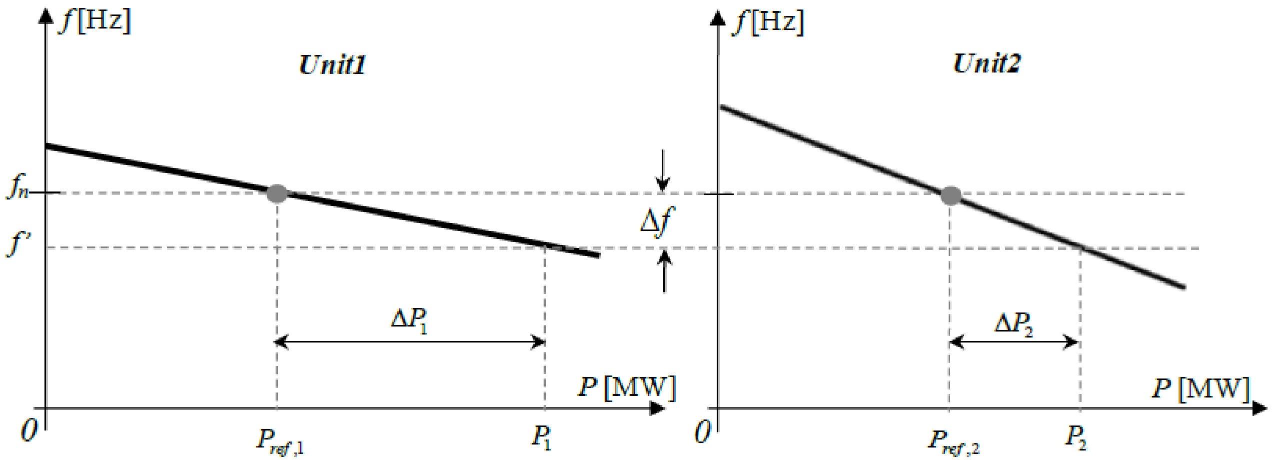
Tertiary Control: Acts within 60 minutes- manual control. Restore primary and secondary control reserves to prefault state.



Frequency control in the Danish power system for a fault [1]

[1] A. Hansen, "Introduction to frequency control modeling," Roskilde, Denmark, Tech. Rep., 2012

Primary frequency control



Load sharing between two parallel generating units [1]

Power system balancing with wind power

- **Need:** Share of power from WPPs is increasing. Hence, system inertia is getting reduced. TSO expect WPPs to respond similar to conventional power plants for frequency deviations.

  - Inertia Control
  - Primary Frequency Control
  - Secondary Frequency Control

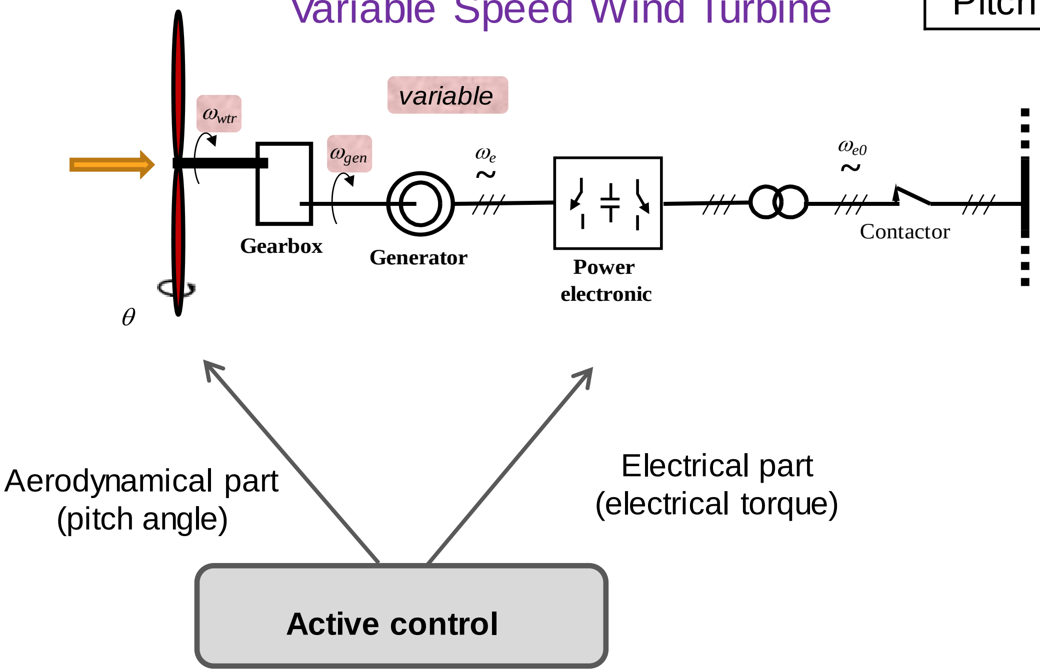
Wind power basics

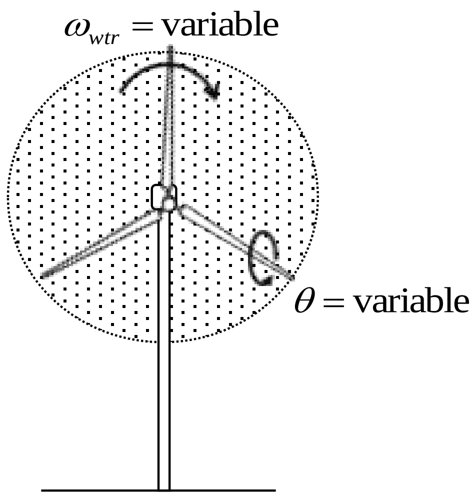
Aerodynamic Power $$P_{wtr} = \frac{1}{2} \rho \pi R^2 U^3 C_p(\lambda, \theta)$$

Tip speed ratio $$\lambda = \frac{\omega_{wtr} \cdot R}{U}$$

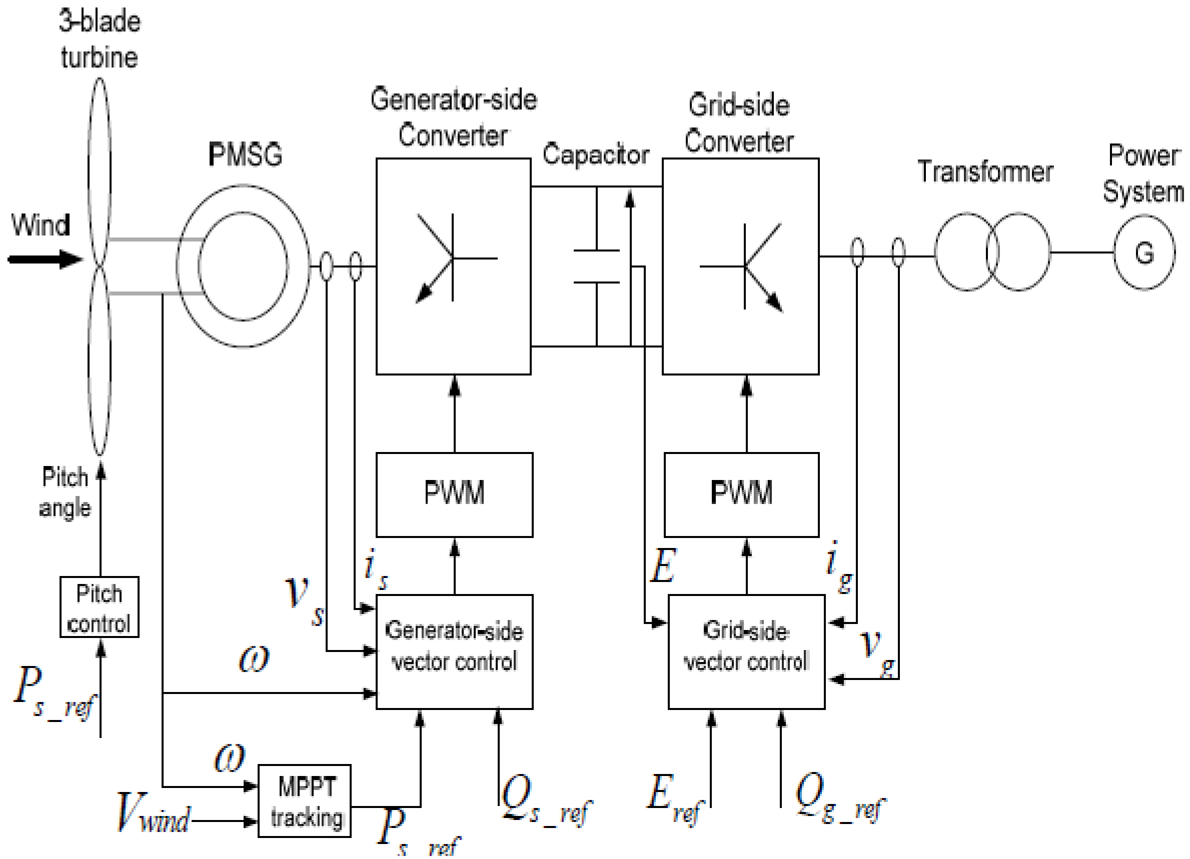
Wind turbine concept	Rotational speed	Pitch angle
Passive stall control wind turbine	fixed	fixed
Active stall control wind turbine	fixed	variable
Pitch control wind turbine	variable	variable

Variable Speed Wind Turbine





Control of wind turbine with PMSG and full scale converter



Block diagram of wind turbine with PMSG and a full scale converter [2]

[2] Weihao Hu, Chi Su, Jiakun Fang ,Zhe Chen,Y.Hu ''Ancillary Frequency Control of Direct Drive Full-Scale Converter Based Wind Power Plants,'' IEEE PowerTech, Grenoble, June 2013,

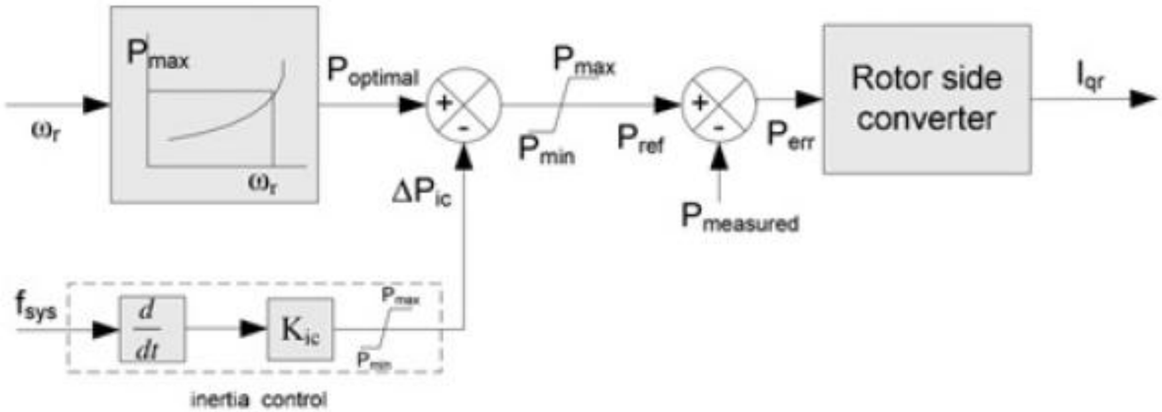
Inertial response of wind turbines

- The kinetic energy stored in the wind generator, the turbine and the blades

$$E_k = 1/2 J \omega_r^2$$

- The power that can be extracted from the rotating mass is [3]

$$P = \frac{dE_k}{dt} = J\omega_r \frac{d\omega_r}{dt}$$



[3] H.T.Ma, B.H.Chowdary"Working towards frequency regulation with wind plants: combined control approaches," IET Renew Power Gen.,2010,vol.4,issue 4, pp.308-316

Primary frequency control of wind turbines

- Using droop control – A power reference to compensate frequency change is generated.

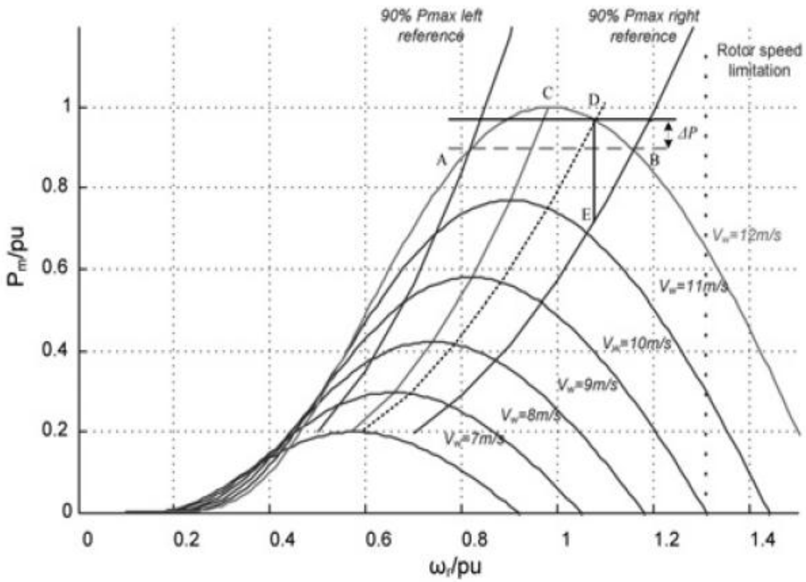
$$\Delta P = 1/R(f_{sys} - f_{ref})$$

Method of creating power reserve: Deloaded power curve

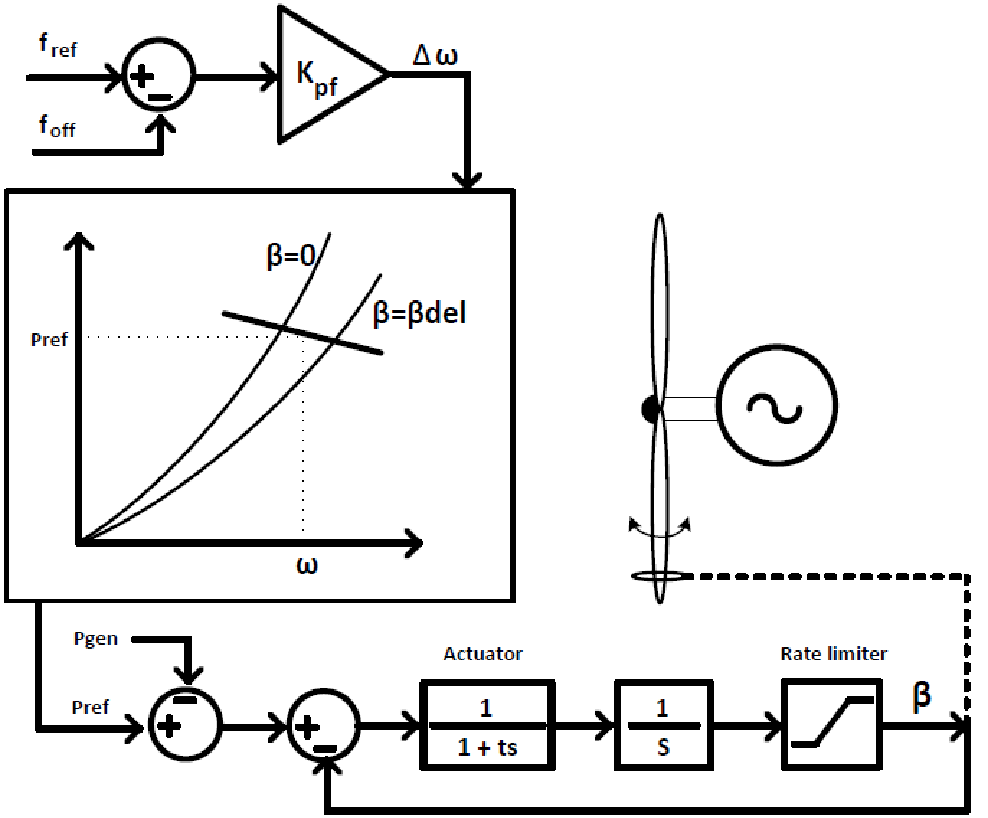
By working along the 90% curve, the wind turbine is forced to generate less power than the maximum power available. Hence, there is a power reserve available for primary frequency regulation.

Decrease in grid frequency causes decrease in speed, hence, increase in power reference.

The speed control can be performed either by rotor speed control (torque) or by pitch angle control.



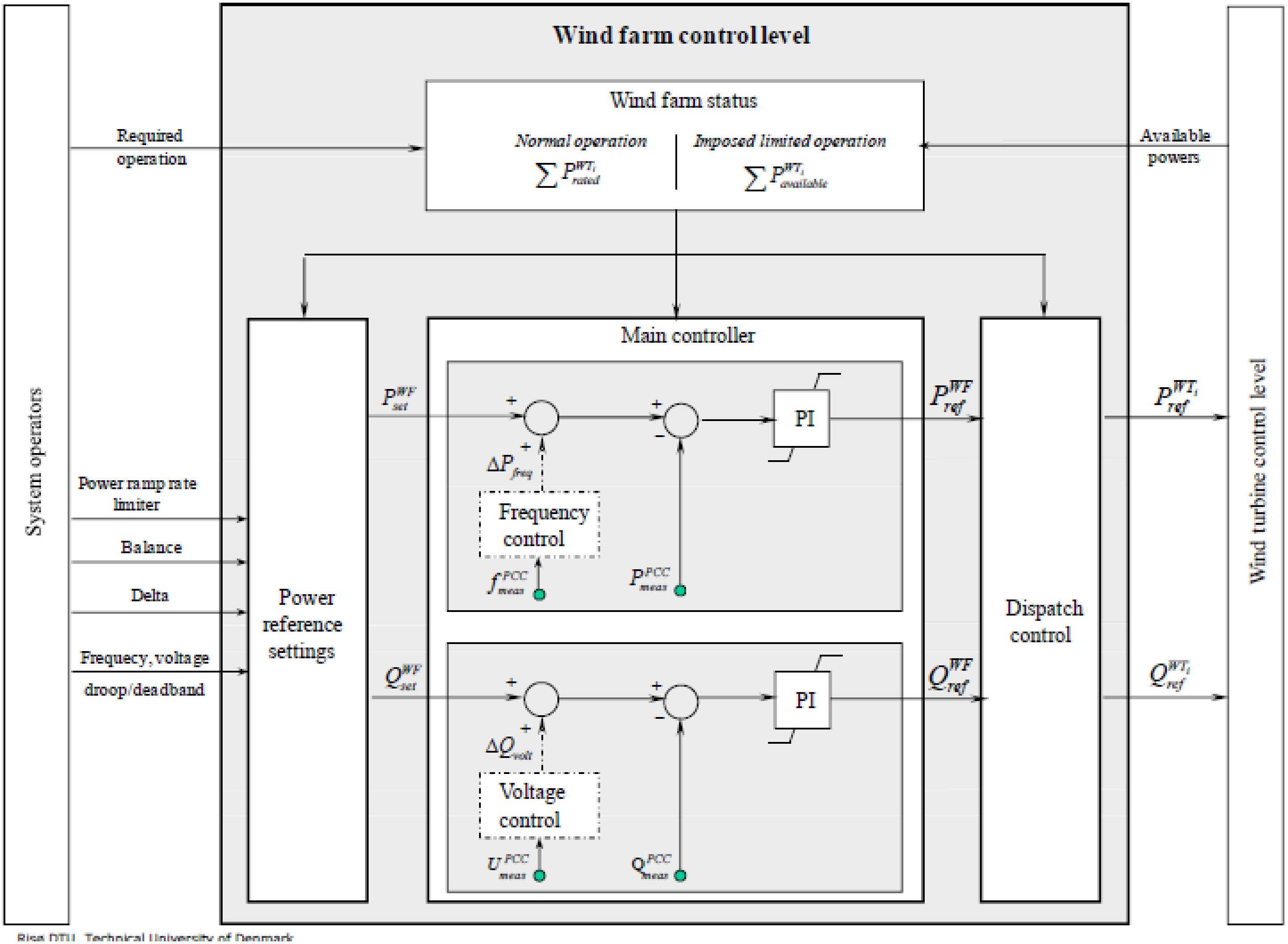
Frequency control by pitch control (Secondary Control)



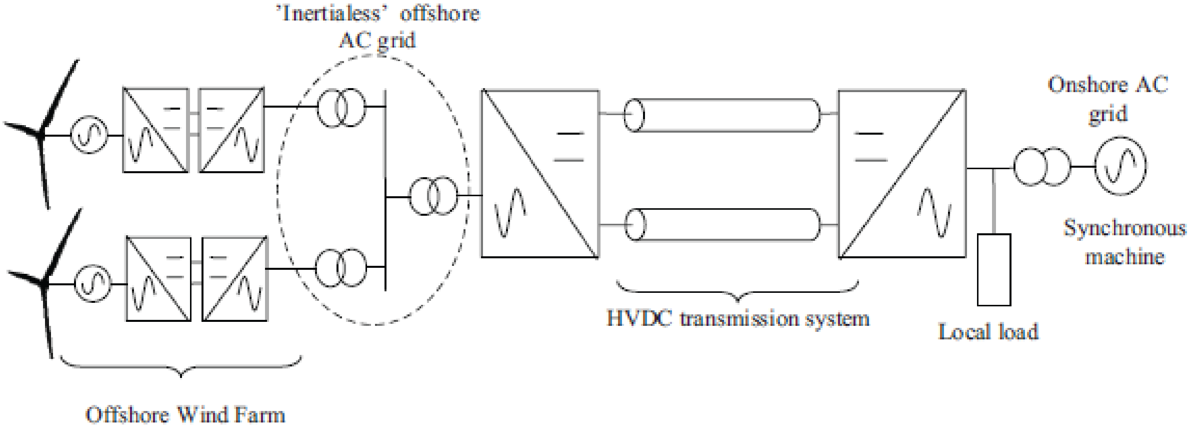
Wind turbine with pitch angle controller [4]

[4] B. Silva‘‘Multi-terminal HVDC Grids: Control Strategies for Ancillary Services Provision in Interconnected Transmission Systems with Oshore Wind Farms”, PhD Thesis, Uporto, Dec 2013

Control of wind power plant



VSC-HVDC connected offshore WPPS

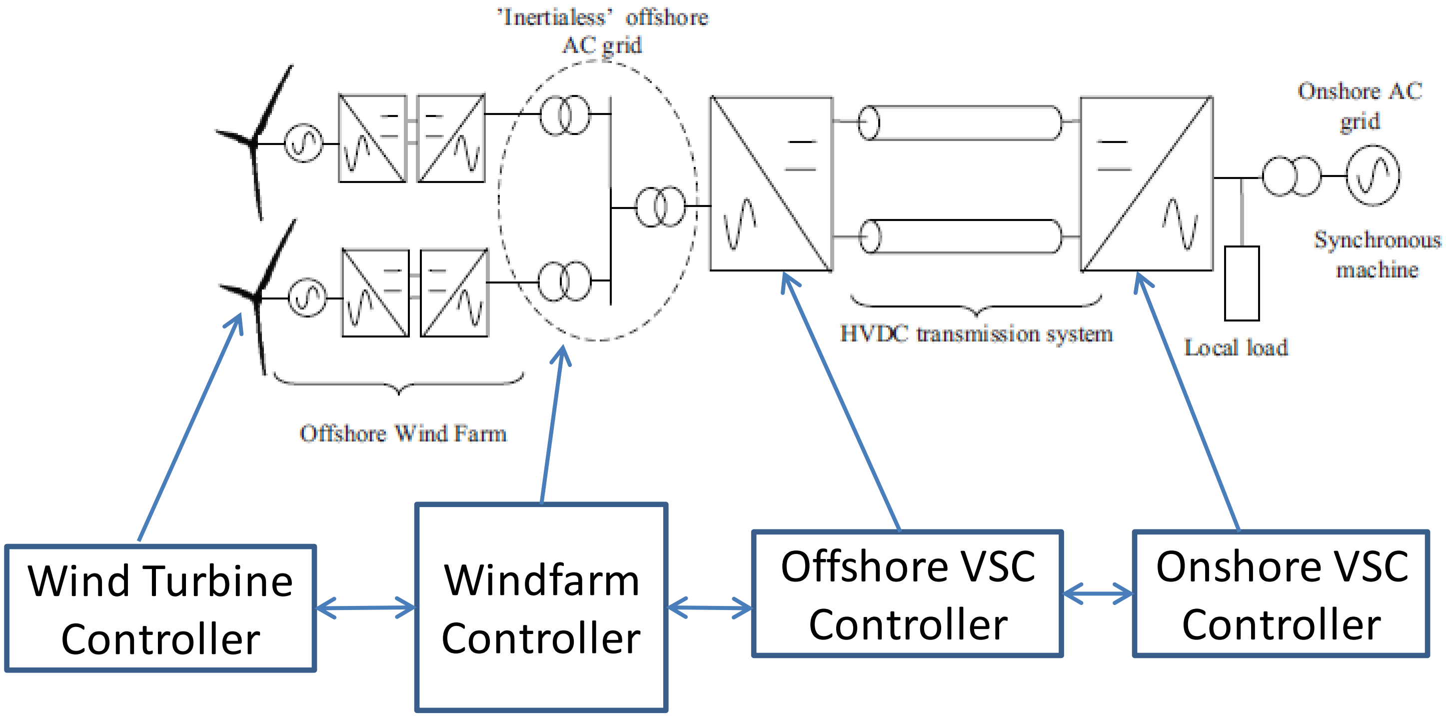


Reasons for opting HVDC over AC for offfshore WPPs [5]

- DC line losses are lower
- AC cables experience a high charging current which limits their length
- Long AC cables at very high voltages are difficult to construct and expensive
- HVDC offers an inherent active and reactive power control, making it more flexible in use and easier to limit overloads in the system

[5] D. Van Hertem, M. Ghandhari , ''Multi-terminal VSC HVDC for the European Supergrid: Obstacles,''Renewable and Sustainable Energy Reviews 14 (2010) 3156–3163

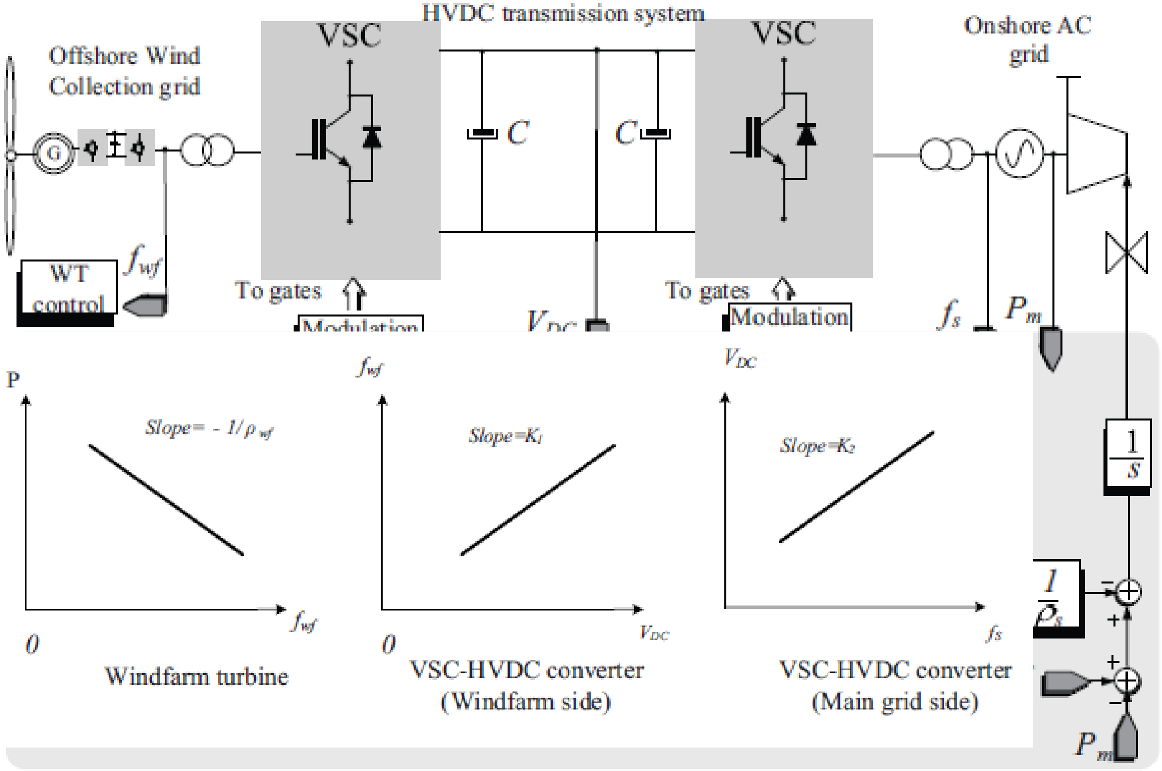
Frequency control strategy for VSC-HVDC connected offshore WPPS [6]



- Frequency Control by Communication
- Frequency control by coordination of different controllers (without communication)

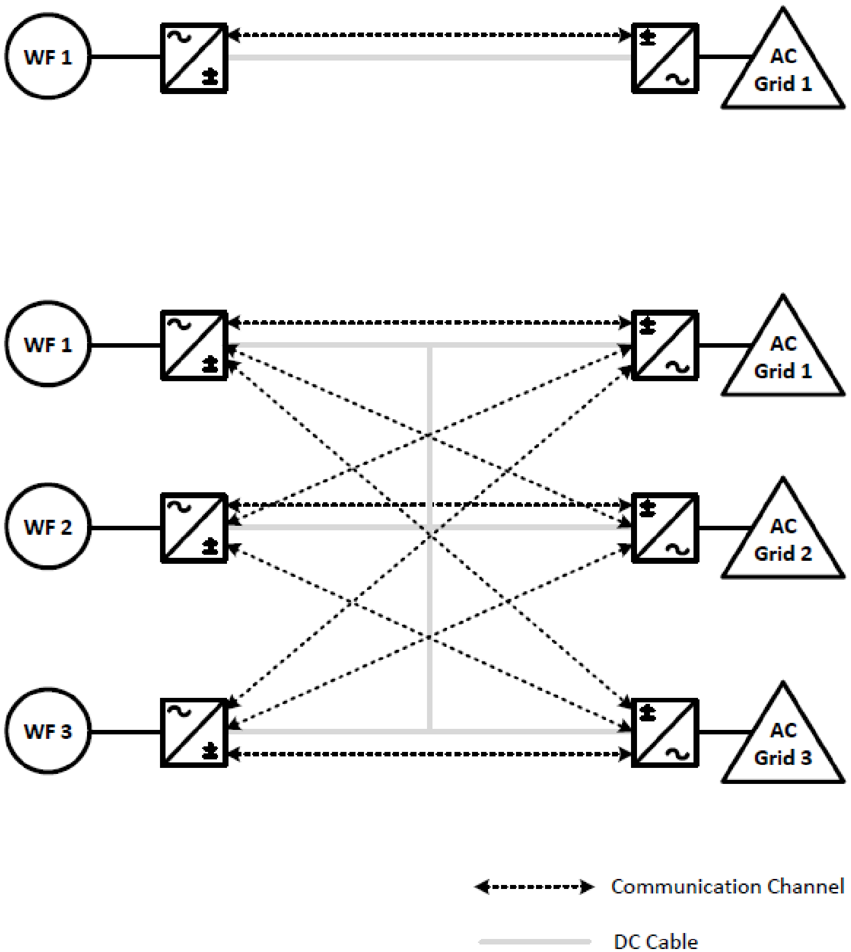
[6] Temesgen M. Haileselassie, Raymundo E. T.O., T.K. Vrana., K. Uhlen, T. Undeland, ''Main Grid Frequency Support Strategy for VSC-HVDC Connected Wind Farms with Variable Speed Wind Turbines,'' In Power Tech, 2011 IEEE Tondhiem.

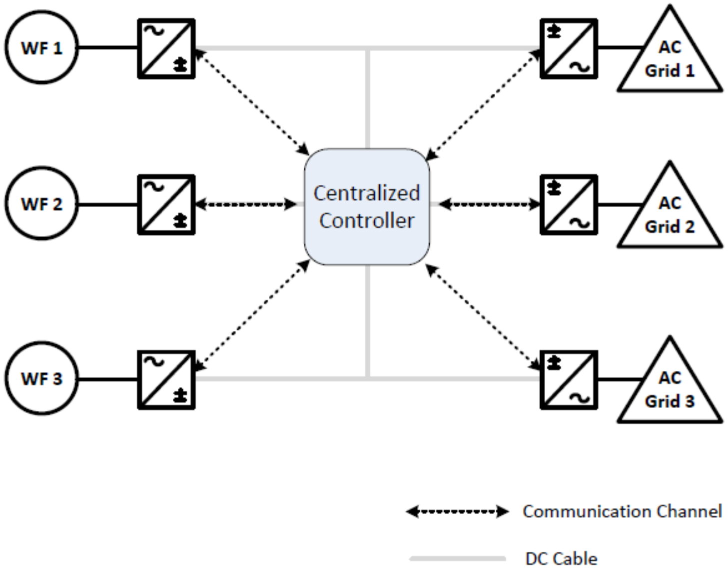
Coordinated control of VSC-HVDC and WPPs control [6]



Droop control method for frequency coordination between onshore and offshore AC Grids

Challenges in Control of WPPs connected in offshore HVDC Grid (Communication based) [4]





- The point to point communication for DC Grid is not economically feasible.
- Reliability is also less
- Inertial emulation is not possible because of communication delay

Challenges of ancillary services control from offshore WPPs in HVDC Grid

- The power system inertia is reduced due to WPPs and HVDC
- Communication/Coordination of controllers is needed to replicate the onshore grid frequecny for inertial and primary frequency control. But synchronous generators act without communication
- Chances of mal-operation of controllers due to noise.
- Inertial emulation is not possible because of communication delay
- HVDC converter controllers are fast compared to WPP control. Hence coordination of controllers is necessary.

Project Plan

- State of the art WPPs control, VSC HVDC grid control
- Modeling of WPPs connected in point to point HVDC system. Designing coordinated control strategies for onshore frequency and other ancillary services ,fault ride through, power oscillation damping.
- Modeling of WPPs connected in HVDC Grid. Designing control strategies to provide ancillary services.
- Validation of proposed control strategies through simulations.
- Validation of the developed control strategies on the laboratory experimental test set up.

Thank You

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