WinGrid Training Workshop
June 2021

Wind Power Capabilities to provide ancillary services

Anca D. Hansen

Outline

- **Definition and types of ancillary services (AS)**
- **Wind power plant (WPP) architecture**
- **Ancillary services from WPPs – research results**
  - Active and reactive power control
  - Voltage and frequency control
  - Enhanced ancillary services
    - Fast frequency control (also referred as Temporary frequency control TFR)
    - Power oscillation damping (POD)
    - Blackstart capability (BS)

Definition of ancillary services

- **Why ancillary services?**

- **CIGRÉ report** - overview of International Practices
  - **definitions** for AS can **differ significantly** based on who is using the terms:
    - some emphasize the importance of AS for **system security and reliability**
    - other mention the use of AS to **support electricity transfers from generation to load** and to **maintain power quality.**
  - some definitions limit the contribution of AS to the **transmission network**, while others include distribution purposes as well.

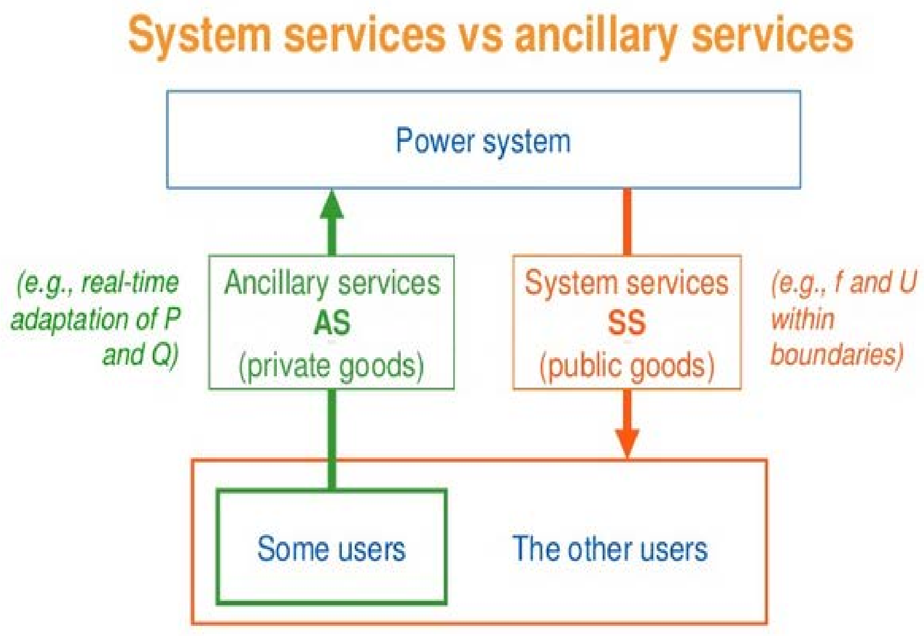
- some of services required to ensure the power system stability are **embedded in conventional power plants** using directly grid connected synchronous generators.
- **Need for enhanced ancillary service** products to ensure stability in power systems with large scale penetration of renewables.

Definition of ancillary services

Focus: on ***system security*** and ***reliability***
the most widely accepted among transmission system operators

- <u>System services</u>
  - frequency and voltage services
  - delivered by the power system **to all** the users.

- <u>Ancillary services</u>
  - are ancillary to the production or consumption of energy
  - provided by some components like generators, controllable loads and/or network devices.



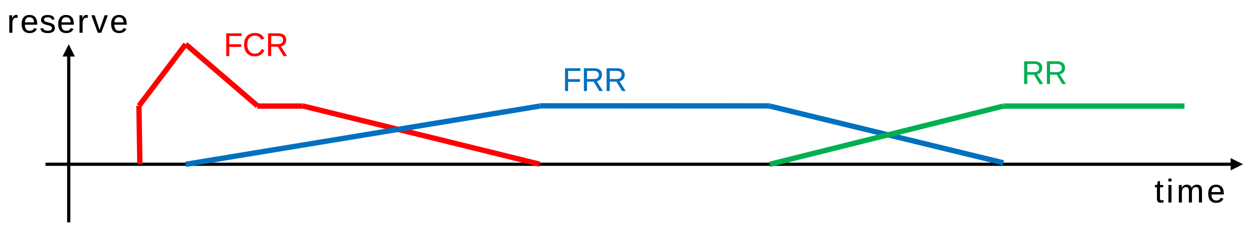
http://www.reservices-project.eu/

Types of ancillary services

- most commonly discussed ancillary services belong to the **active power reserves**
- **CIGRÉ report** (based on the sequence in which AS are expected to operate)
  - primary frequency control
  - secondary control
  - tertiary reserves
  - voltage control
  - black start services
- **In Denmark – Energinet** classifies AS in:
  - frequency-controlled reserves
  - secondary reserves
  - manual reserves and regulating power
  - other properties for ***maintaining*** power system ***stability***
    - Short-circuit power
    - Continuous voltage control
    - Voltage support during faults
    - Inertia

Types of ancillary services

- **European transmission system operators (ENTSO) report**
  - **Frequency containment reserves** (FCR)
  - **Frequency restoration reserves** (FRR)
  - **Replacement reserves** (RR): “regulating reserve”



REserviceS project: benefits of getting ancillary services from WPPs increase with their penetration

- **Enhanced ancillary services products**
  - Fast frequency response (and inertia support)
  - Synchronising power
  - Power oscillation damping
  - Black – start capability

Grid code requirements

- **Technical capabilities of WPPs** to provide AS are commonly required **in grid codes**
- First grid code dedicated WPPs was introduced in **Denmark (2000)**
  - the first large offshore WPP connected directly to transmission system
  - only AS was: remotely control of power setpoint
  - special power control in the case of frequency transients was not a general requirement
  - the first large offshore WPP in Horns Rev was capable of providing frequency support
- In later grid codes - added requirements:
  - frequency control
  - reactive power
  - voltage control capabilities
- New common **European ENTSO-E Network Code** also includes
  - power oscillation damping
  - synthetic inertia

Danish Grid Codes

- **Fault Ride Through Capabilities** – addresses individual wind turbine controller
- **Power control Capabilities** – active power/frequency & reactive power/voltage control

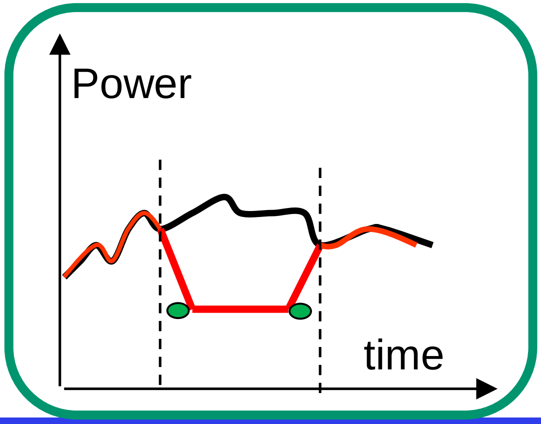
Active power control functions

- Balance control
- Delta control
- Power gradient limiter
- Automatic frequency control

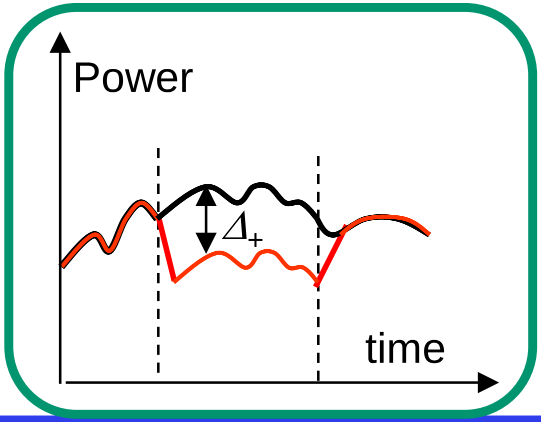
Reactive power control functions

- Reactive power control
- Automatic voltage control

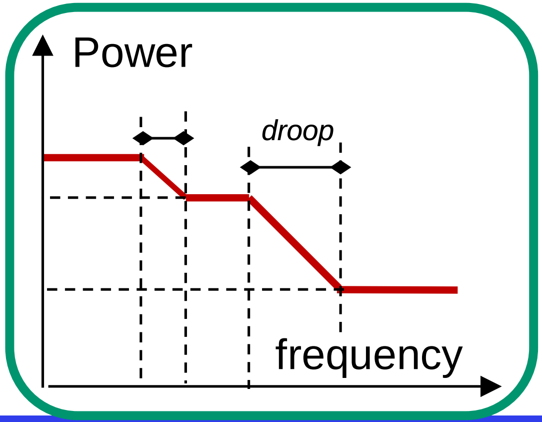
Balance control



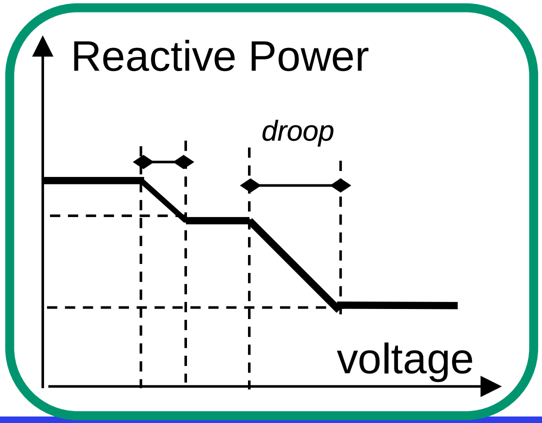
Delta control



Frequency control



Voltage control



Wind farms with power plant characteristics

Traditionally: **produce energy at the lowest possible cost**

- to produce maximum possible power
- to reduce the structural loads on the mechanical components and thus theirs costs

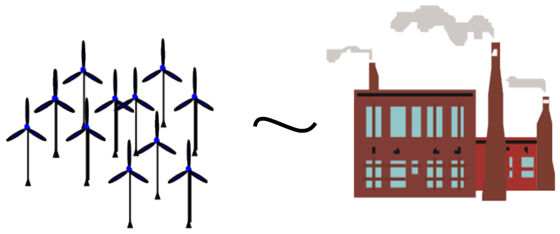
Additionally now: **active controllable components supporting the grid**

- to provide grid support to secure power system quality, stability and reliability
- to reduce the required grid connection costs

WPPs technical capabilities to provide AS

- **Wind power plants**

  wind farms with power plant characteristics supporting the grid



- **Why needed ?**

  to secure quality, stability and reliability of the power system with large wind power

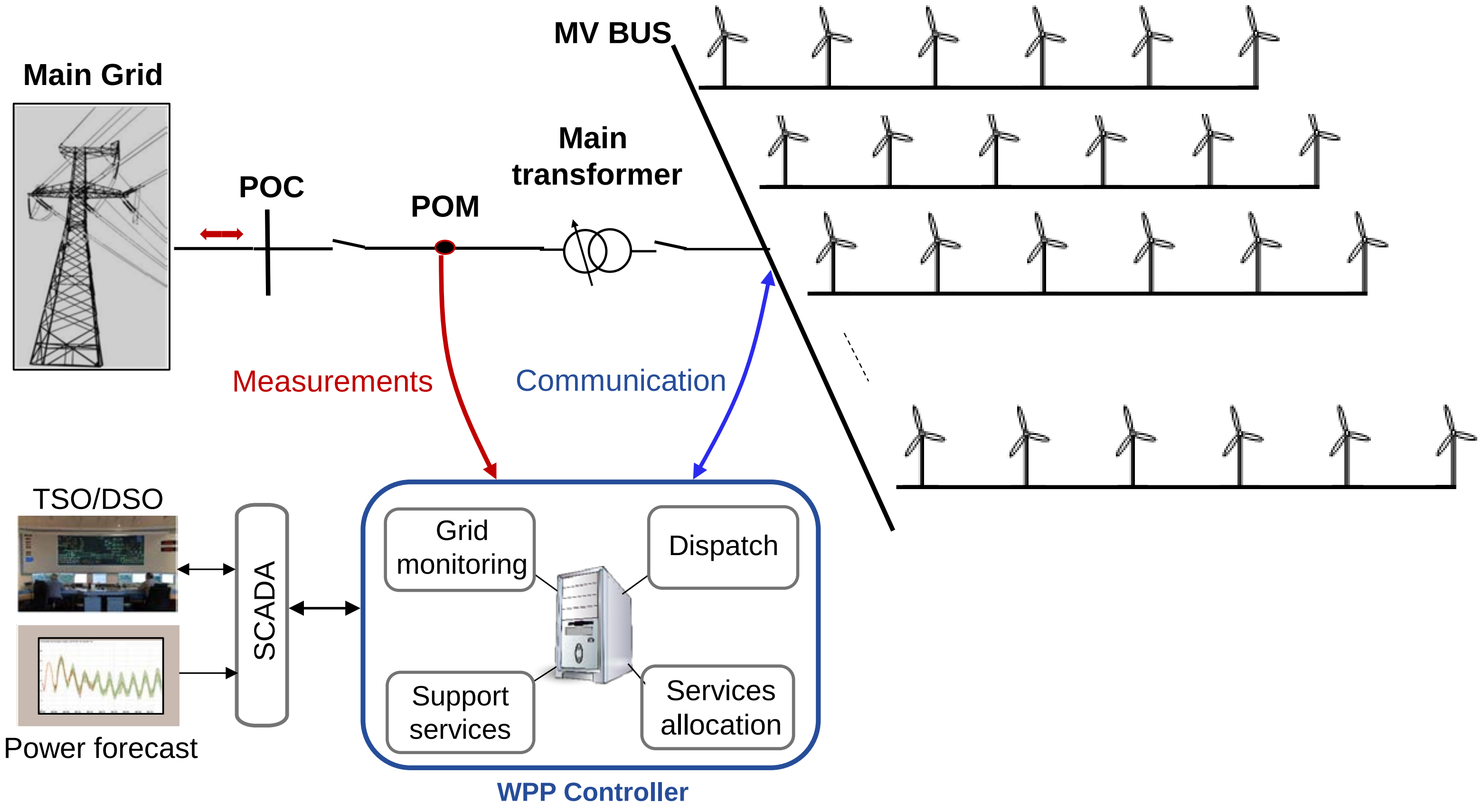
- **How ?**
  - develop dynamic models & control solutions for enabling wind power to replace *conventional power plants*
  - optimize WPPs interaction and participation in the power system control according to the new grid codes.

Wind farm concepts and control:
- Active stall wind turbines
- Doubly-fed induction wind turbines
- PMSG full converter wind turbines

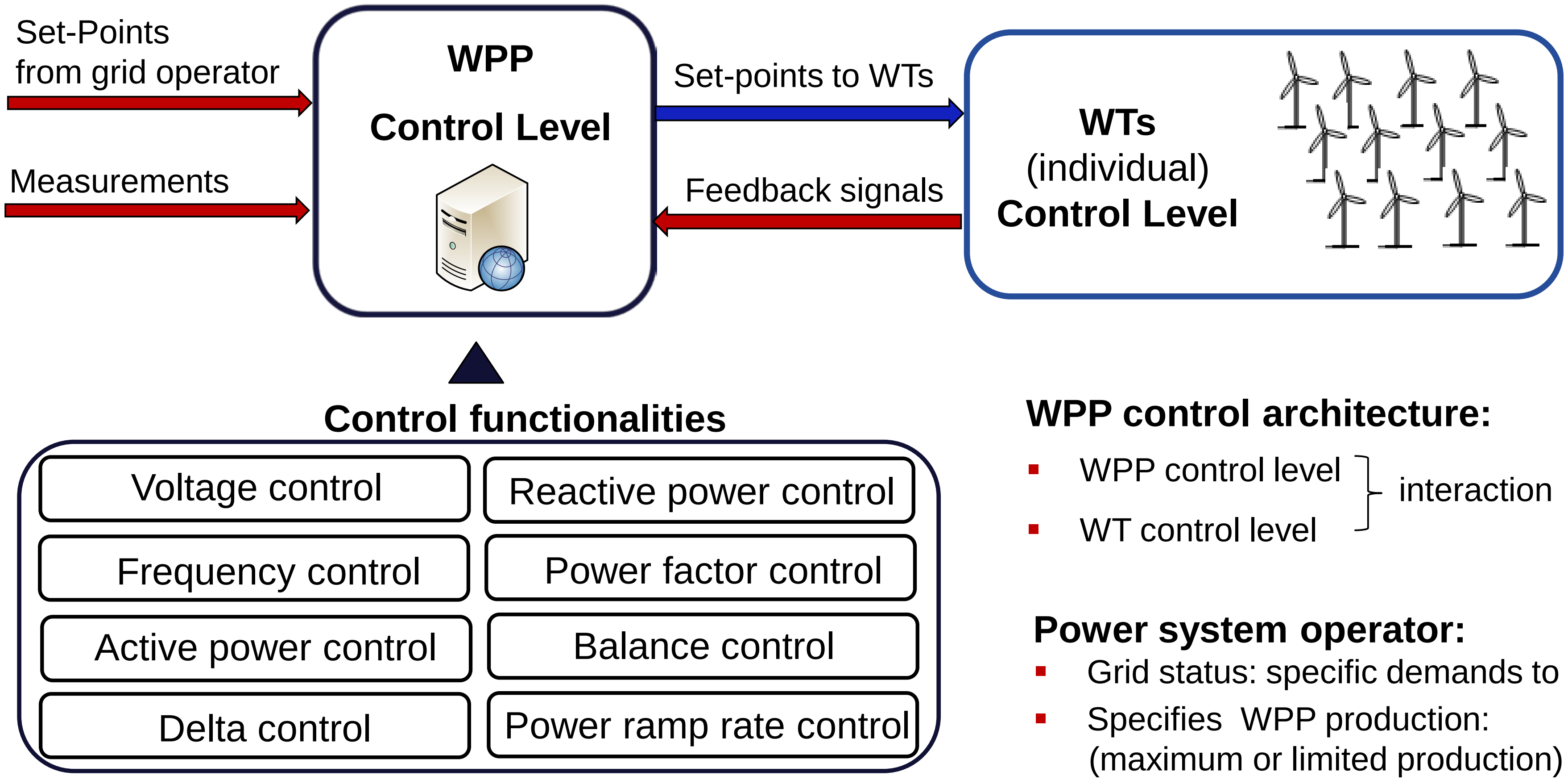
Grid types:
- large and strong
- small and isolated

Modelling approach:
- individual
- aggregated

Wind power plant configuration



Wind power plant control architecture



WPP control architecture:

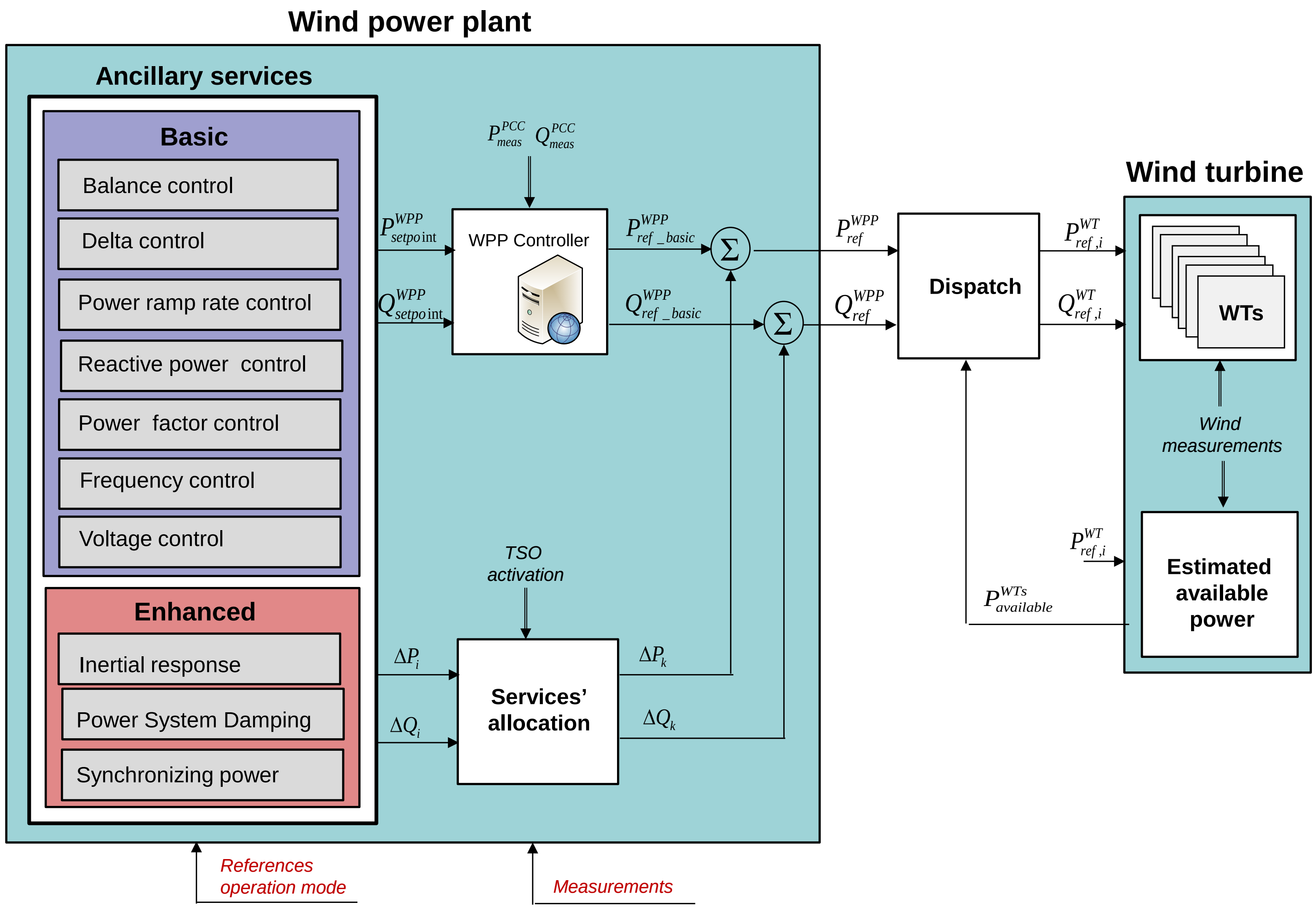
- WPP control level } interaction
- WT control level

Power system operator:

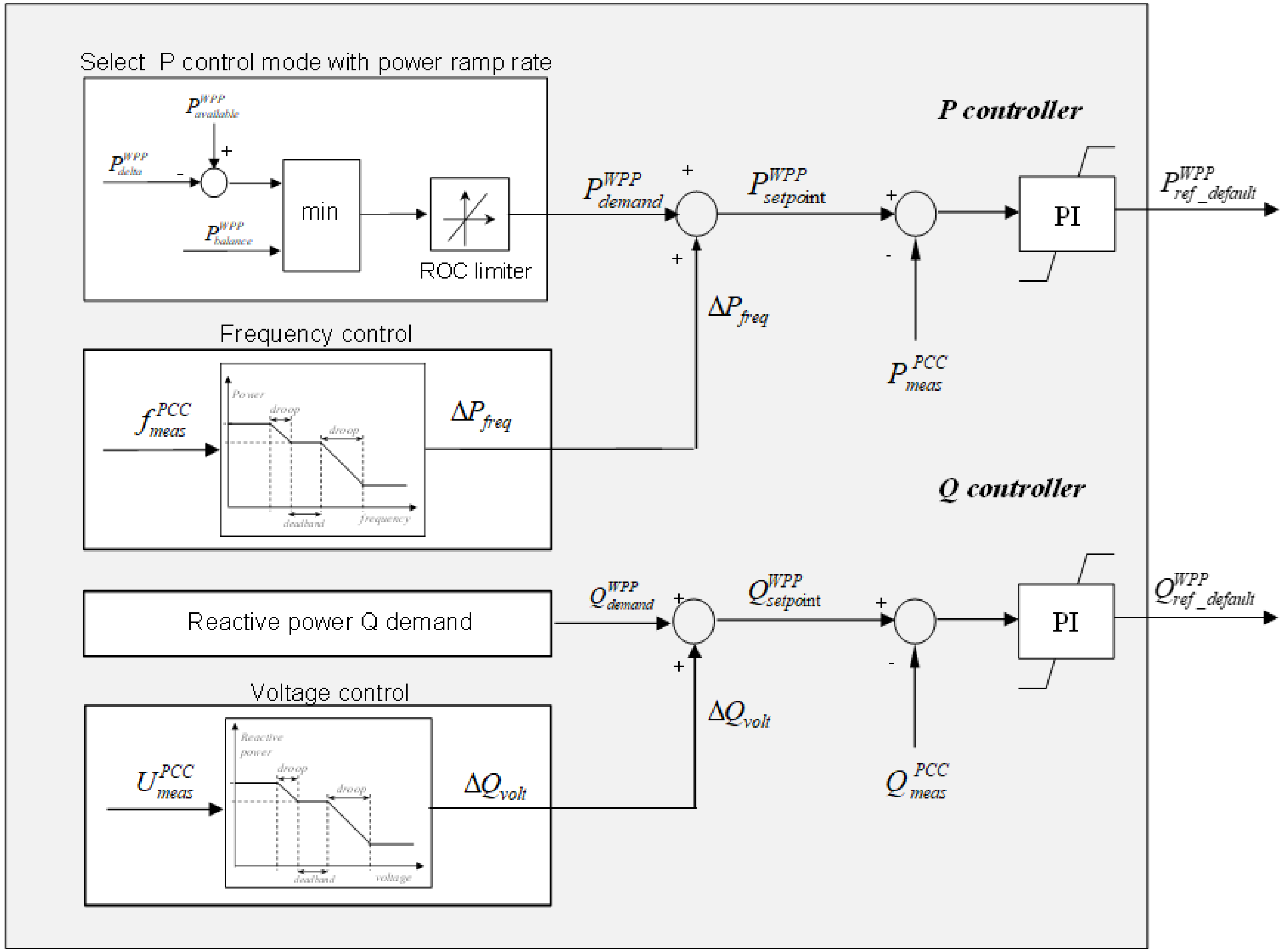
- Grid status: specific demands to WPP
- Specifies WPP production: (maximum or limited production)

Temporary frequency response | Synchronising power | Power system damping

Wind power plant control architecture



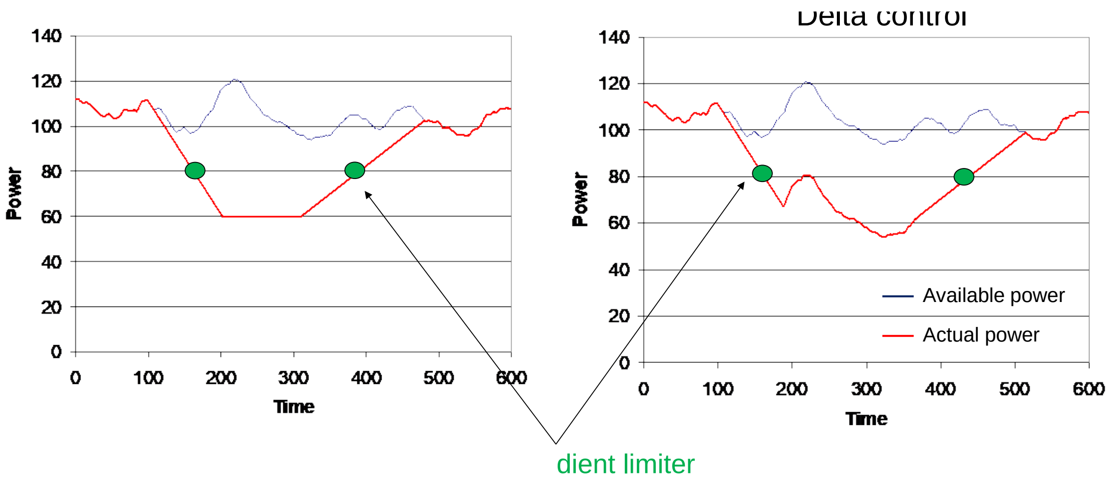
Wind power plant controller with control services



WPP active and reactive power control grid support

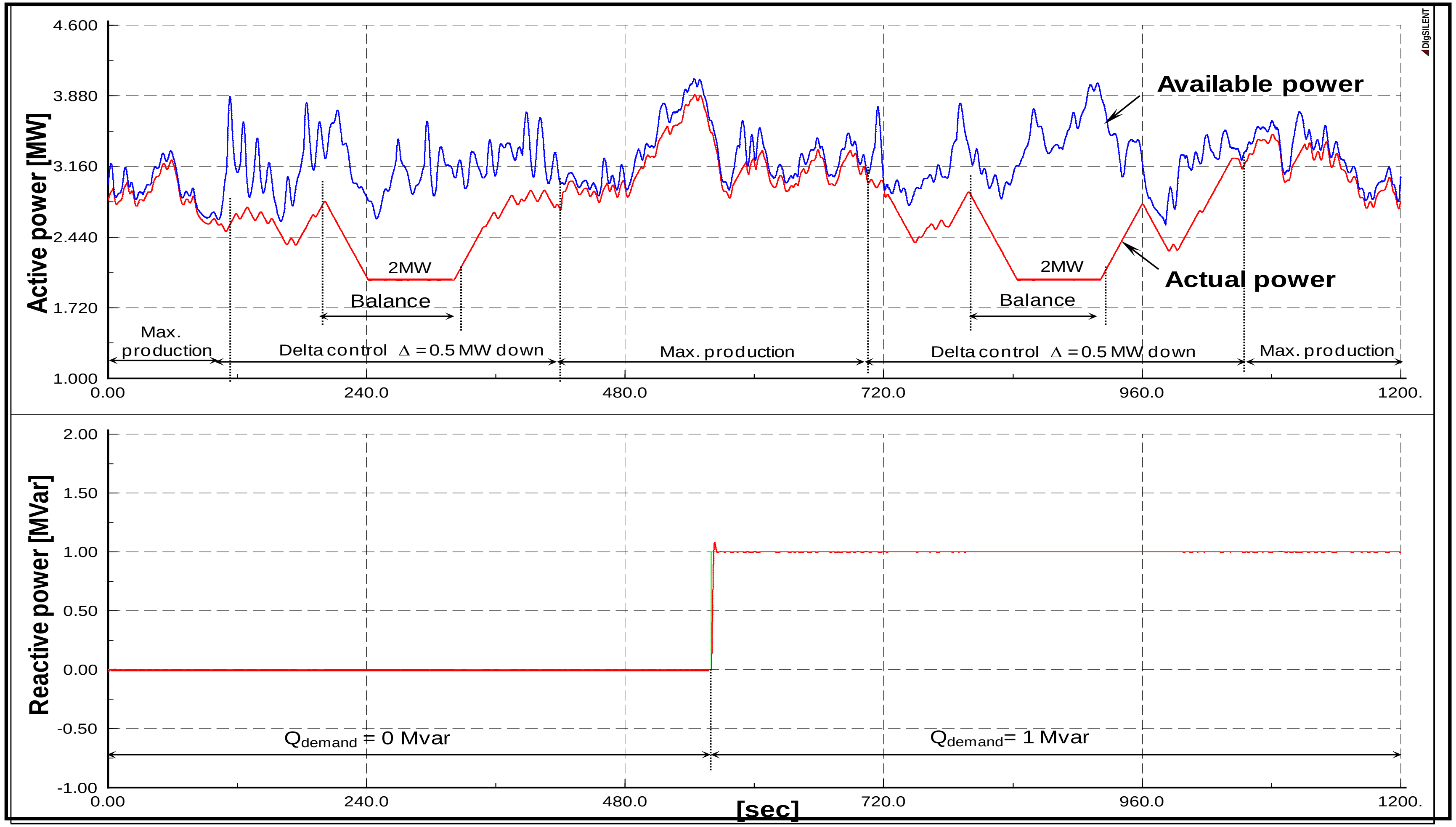
Ability of a WPP to control to regulate downwards and upwards the WPP production to the power reference ordered by the system operators.

- Active power control functions:
  - Balance control
  - Delta control
  - Power gradient limiter



- Reactive power control

WPP active and reactive power control grid support



Centralised power control of wind farm with doubly fed induction generators

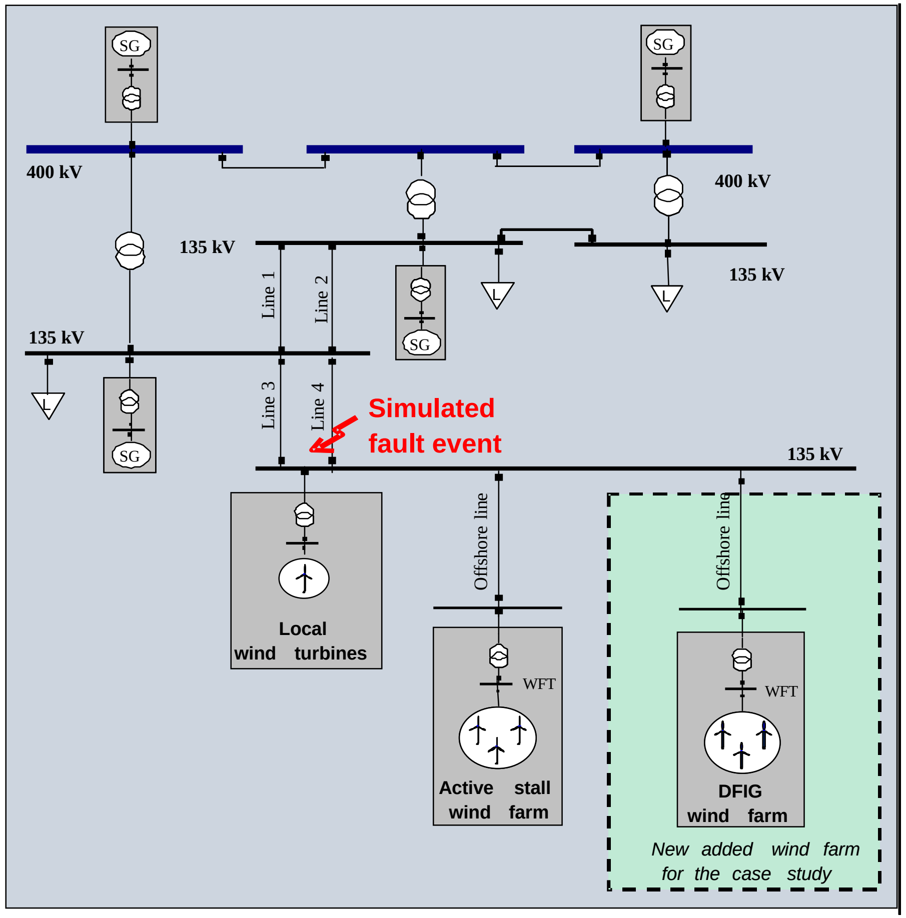
A.D. Hansen, P Sørensen, F Iov, F Blaabjerg - Renewable Energy 31 (7), 935-951

WPP voltage control grid support

Power transmission system model

Danish Transmission System operator EnergiNet.dk

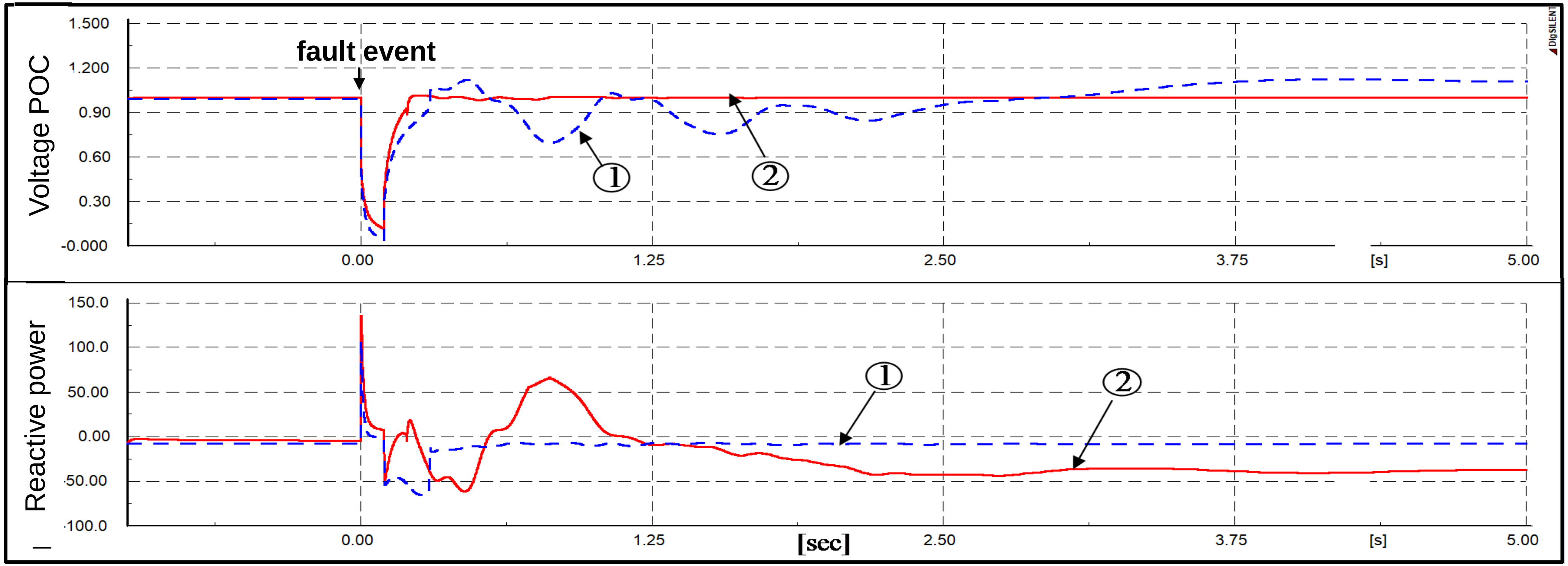
- Voltage grid support capability (Type 3 & 4)
- Impact of voltage grid support from Type 3 & 4 on the performance of a nearby Type1 to FRT



WPP voltage control grid support

Type 3 or 4 WPPs

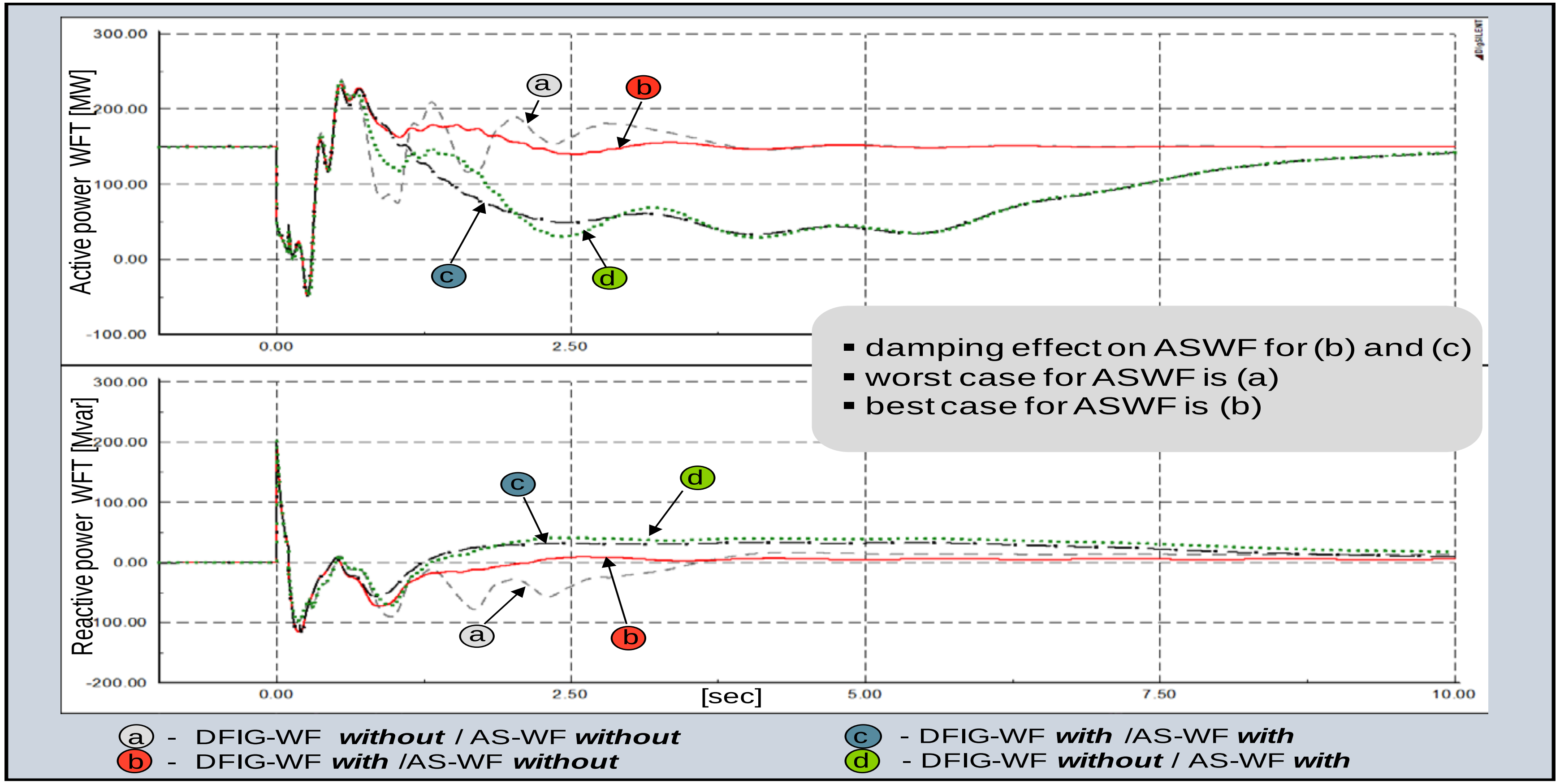
① Without WPP voltage control	② With WPP voltage control



Co-ordinated voltage control of DFIG wind turbines in uninterrupted operation during grid faults

AD Hansen, G Michalke, P Sørensen, T Lund, F Iov - International Journal for Progress and Applications in Wind …

Impact of Type 3 & 4 voltage control support on Type1

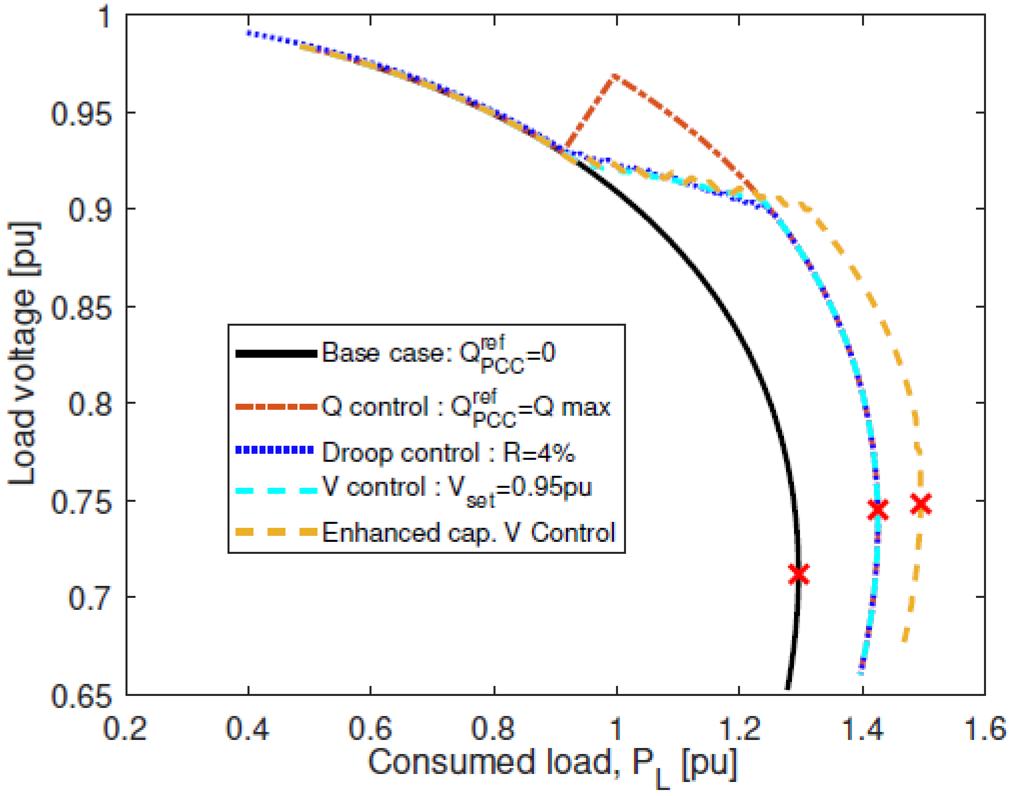


Type 3 & 4 wind turbines can help nearby Type 1 wind turbines to fault ride through, without any additional ride through control setup in the Type 1 wind turbines

Co-ordinated voltage control of DFIG wind turbines in uninterrupted operation during grid faults

AD Hansen, G Michalke, P Sørensen, T Lund, F Iov - International Journal for Progress and Applications in Wind …

WPP voltage control grid support during stressed voltage conditions



Maximum power transfer (pu values on 500 MVA base)

Control strategy	Base Case	Q Control	Droop Control	V Control	Enhanced cap. V control
Value [pu]	1.30	1.43	1.43	1.43	1.50
Increase [%]	-	10	10	10	15.4

Sarkar, M. (2020). Modelling of Wind Power under Stressed Voltage Conditions. DTU Wind Energy. DTU Wind Energy PhD https://doi.org/10.11581/dtu:00000072

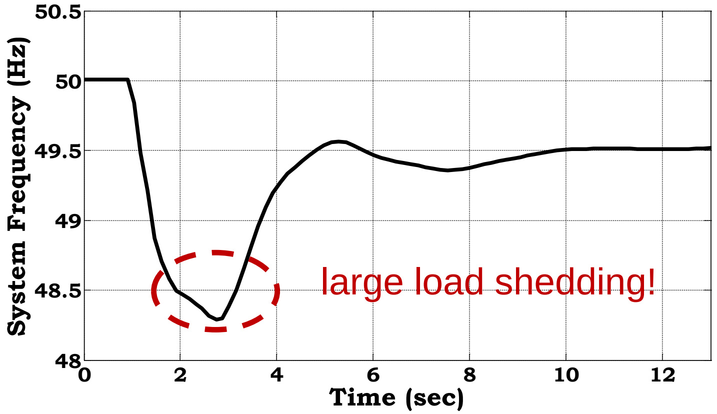
WPP frequency control grid support

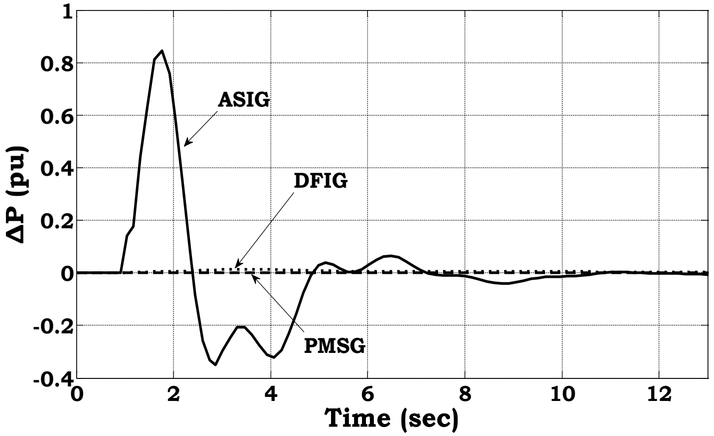
- sudden loss of the largest unit in the system

- with no frequency control in the wind farms, frequency may drop leading to large load shedding

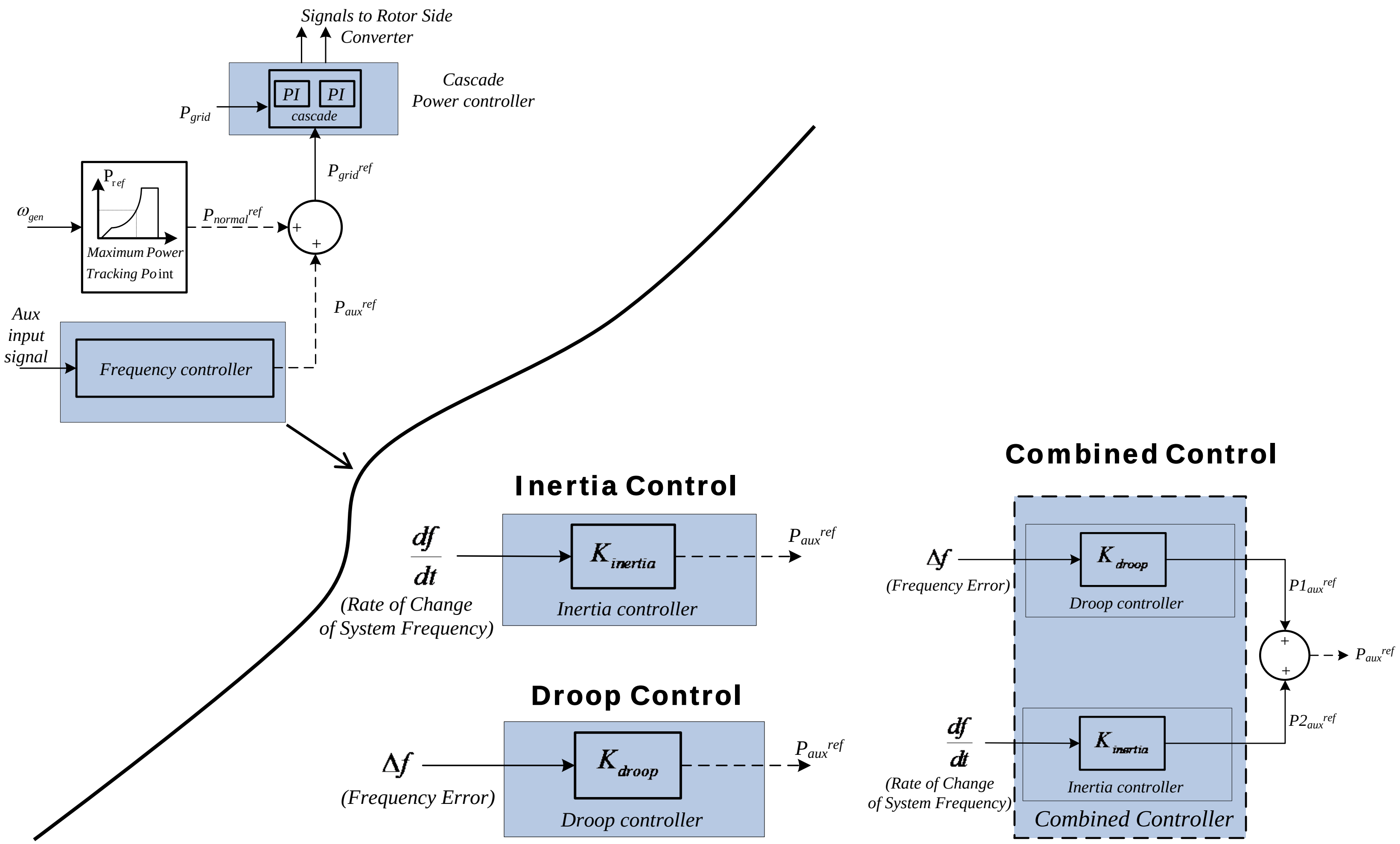
- **Fixed speed WT (Type 1)**:
  - rotor speed attached to the system frequency
  - provides inertial response
  - kinetic energy of the rotor is transformed into electrical energy delivered to the grid

- **Variable speed WT (Type 2 & 3)**
  - decoupled from the power system
  - do not inherently contribute to system inertia

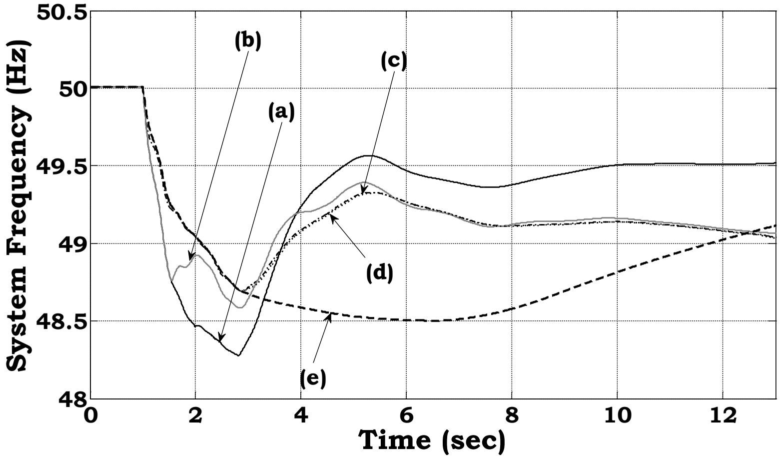




WPP frequency control grid support



WPP frequency control grid support



(a) No auxiliary control

(b) Droop control on WF level

(c) Droop control on WT level

(d) Combined control

(e) Inertia control

Frequency Control Scheme		Minimum Frequency (Hz)	Maximum Rate of change of frequency (Hz/sec)	Load Shedding (MW)
(a)	No auxiliary Control	**48.29**	**-2.8**	15.1 (18%)
(b)	Droop control on WF level	48.58	-2.8	0
(c)	Droop control on WT level	**48.69**	-1.9	0
(d)	Combined Control	**48.68**	**-1.8**	0
(e)	Inertia control	48.52	**-1.8**	0

Short-term overproduction capability

Short-term overproduction capability
depends on the initial pre-overproduction conditions:

- wind speed
- limits of the mechanical/electrical components
- control strategy

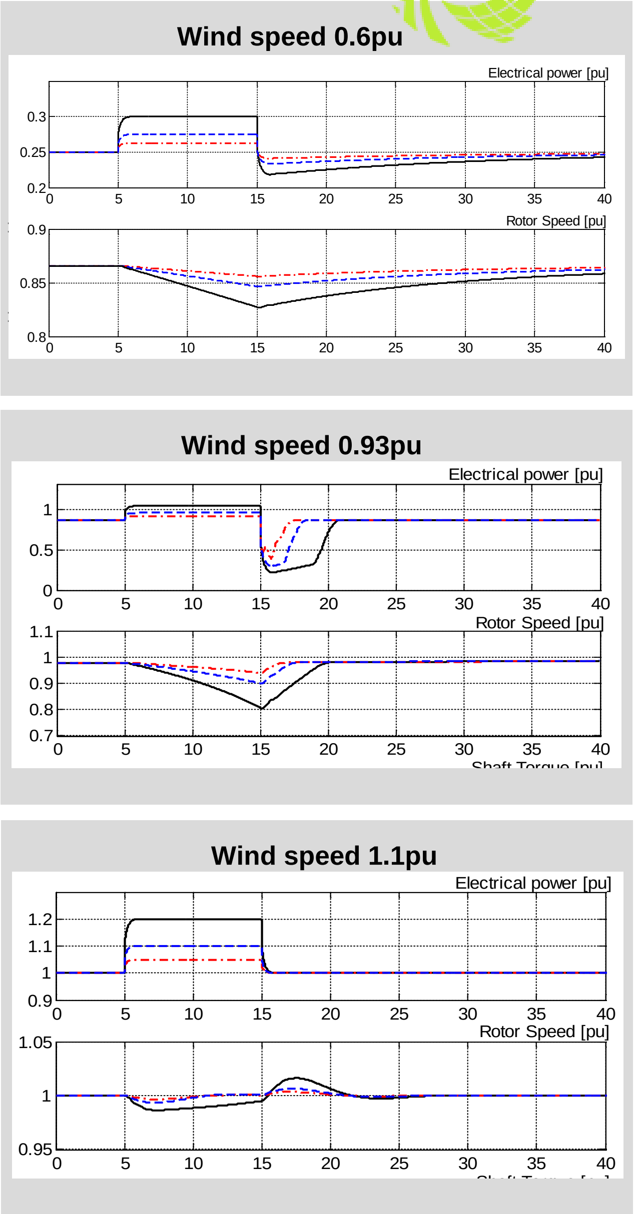
important in the design of a reliable frequency support

Below rated wind speed
the overproduction is followed by a **recovery period** *(turbine re-acceleration)*

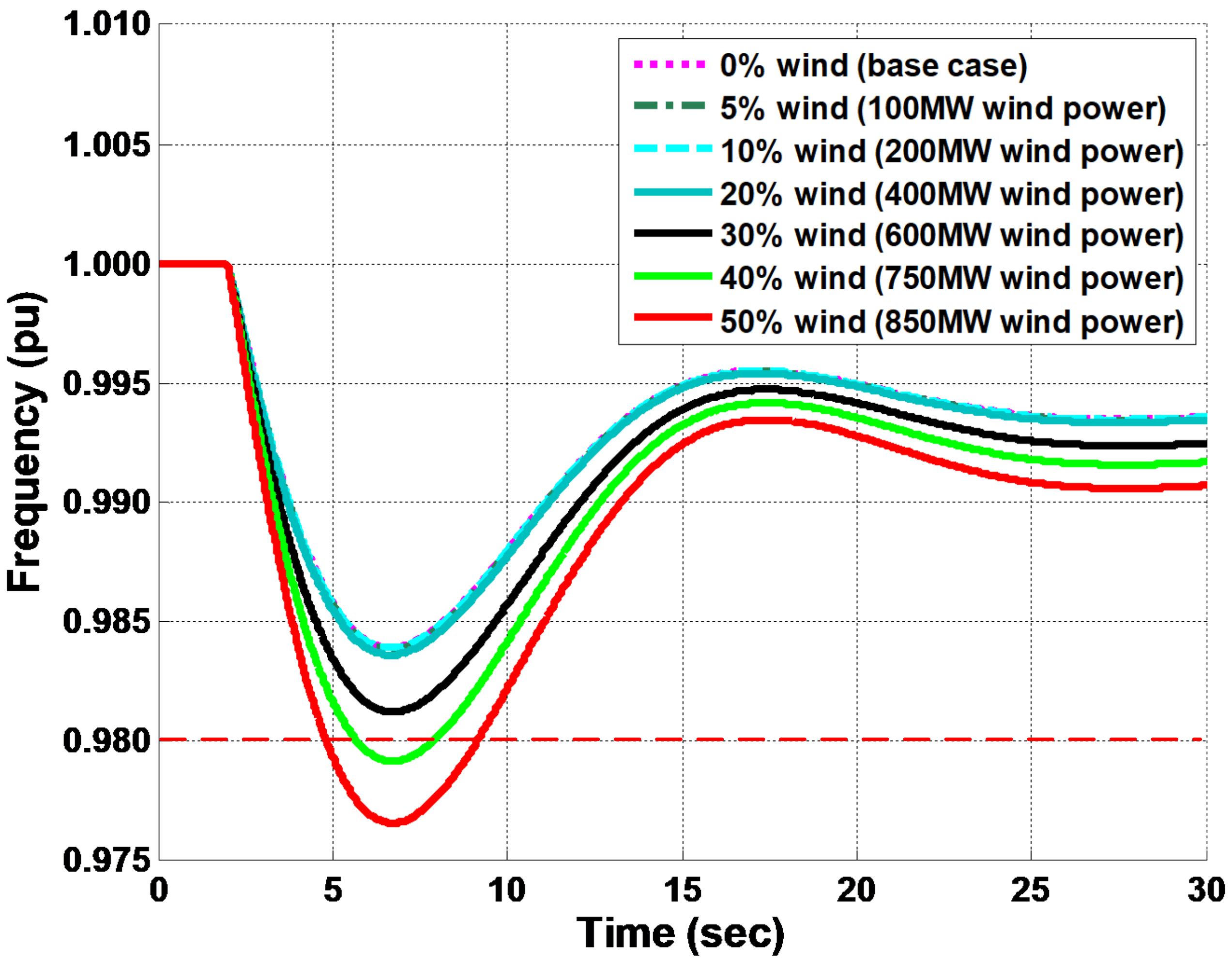
The higher the wind speed, the **shorter** the recovery period.
No recovery above rated wind speed.

The higher the overproduction power:

- the longer the recovery period and the larger the power underproduction *(frequency stability might be affected)*
- the higher the shaft torque *(high mechanical stress of the turbine shaft)*

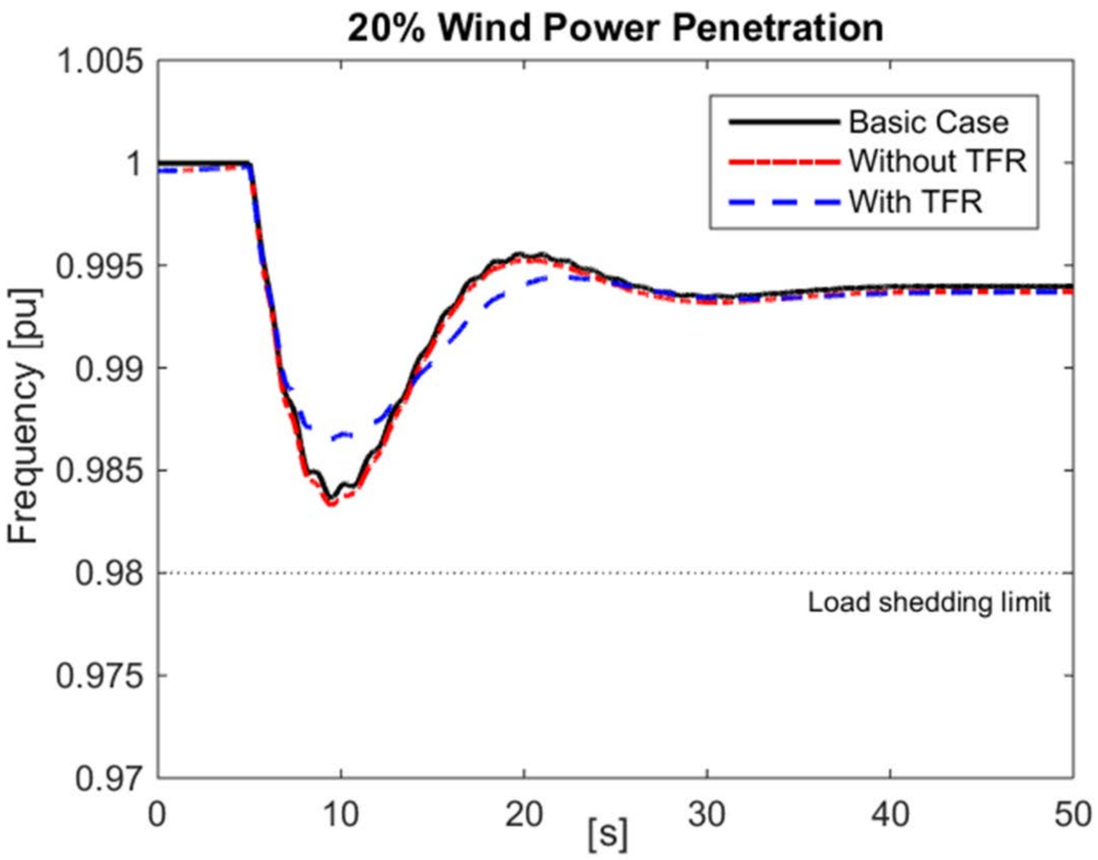


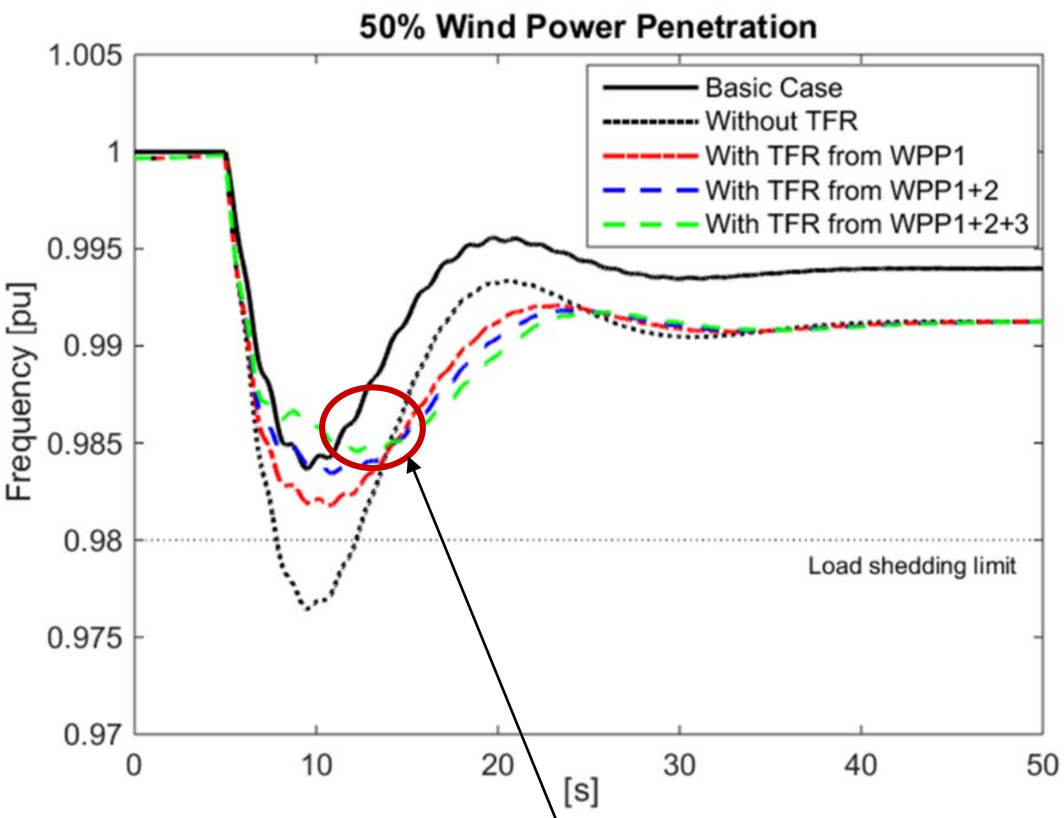
Frequency drop at different wind power penetrations



WPPs temporary frequency response

Loss of the largest unit /different wind power penetrations



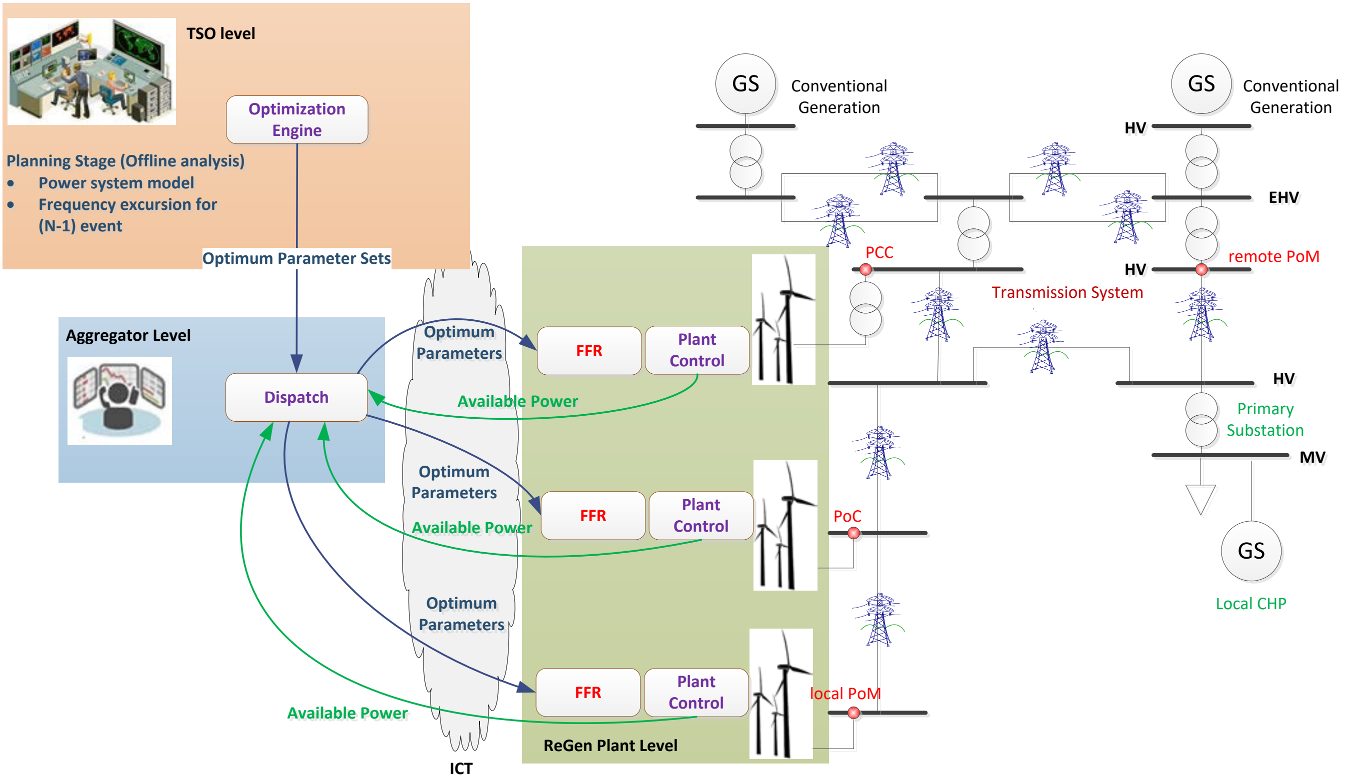


Provision of enhanced ancillary services from wind power plants–examples and challenges
A.D. Hansen, M Altin, F Iov - Renewable Energy 97, 8-18

need for coordination!

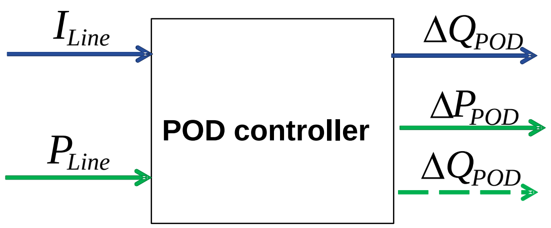
Impact of communication on fast frequency support

- ability to provide fast frequency response (FFR) from WPPs highly depends on the underlying communication infrastructure that allows an exchange of information between different WPPs plants and the control centers

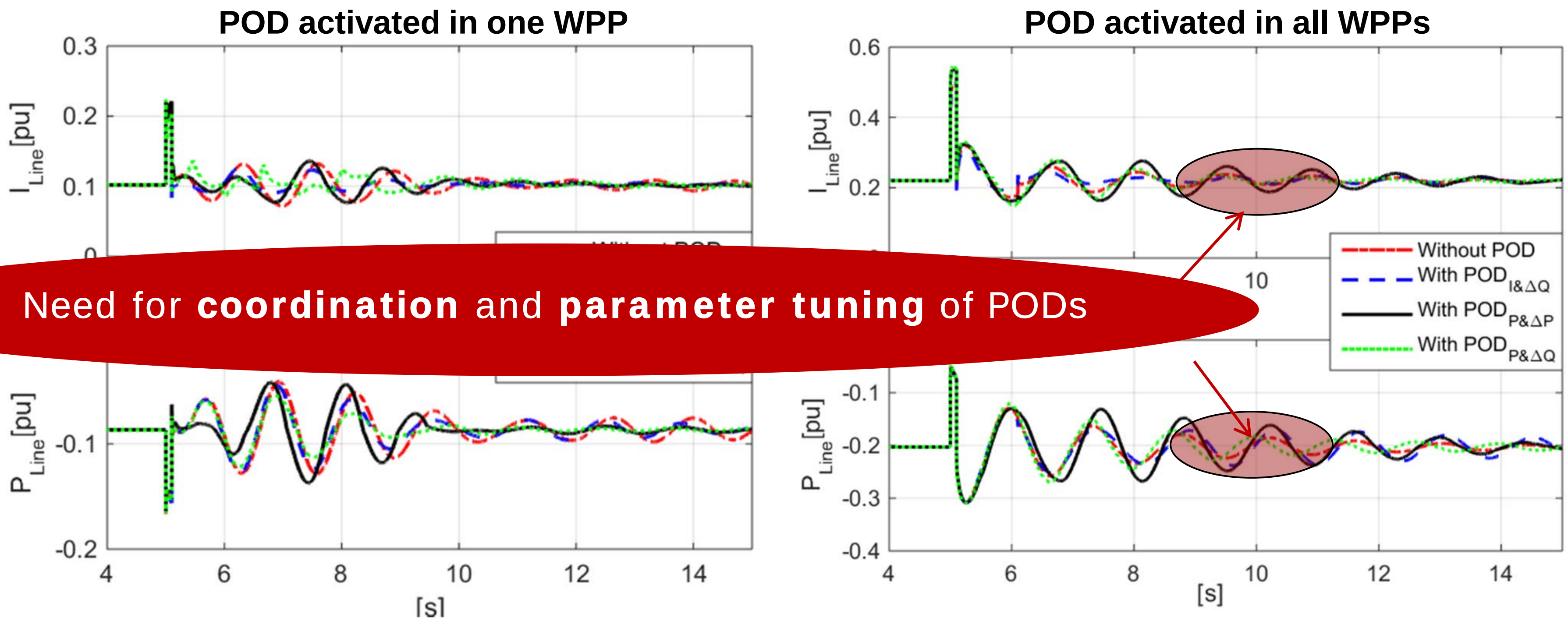


ICT Based Performance Evaluation of Primary Frequency Control Support from Renewable Power Plants in Smart Grids
K Shahid, M Altin, LM Mikkelsen, R Løvenstein Olsen, F Iov - Energies 11 (6), 1329

WPP power oscillation damping capability



- 50% wind power penetration
- different input/output signal pairs
- same POD controller parameters in all WPPs



Need for **coordination** and **parameter tuning** of PODs

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Black start approches/plans
Offshore WPP via the VSC HVDC link

Top-down

- Restart from neigboring interconnected systems
- Preferred and easier apporach, but not always easier

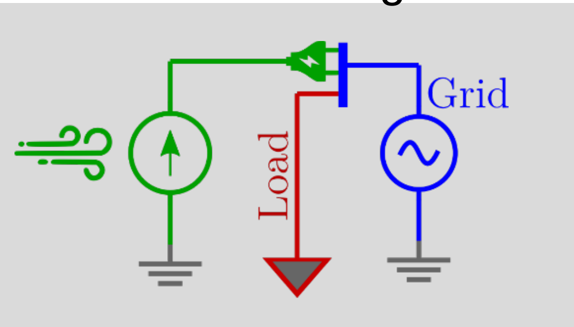
Bottom-up

- Restart with own generators
- Either blackstart capable units or house units
- Energize several islands and then interconnect
- All TSOs should have such a plan

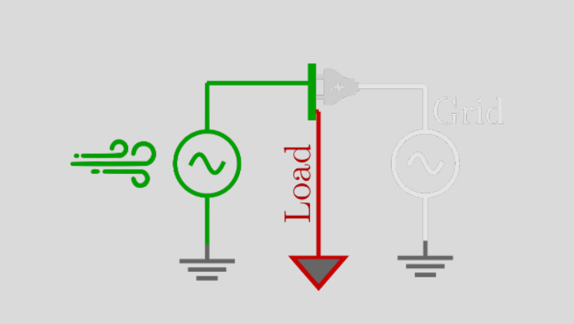
GFL

WPP blackstart capability

Grid following WT



Grid forming WT



Motivation

High volume integration of RES far from loads
Increased trans-national power exchanges
Decreased Var reserve due to SG replacement
Power electronics EMT, Inertial decoupling
Uncontrolled Islanding, Protection settings re-design
Complicated grid operation: stability, reliability

Increased risk of wide-area blackouts
eg: South Australia 2017, UK 2019

TSO

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, green blackstart capability of VSC-HVDC OWPP
Advanced V,f control functionalities from state-of-art PE interface of modern WTs

Grid forming / Blackstart-able WTs

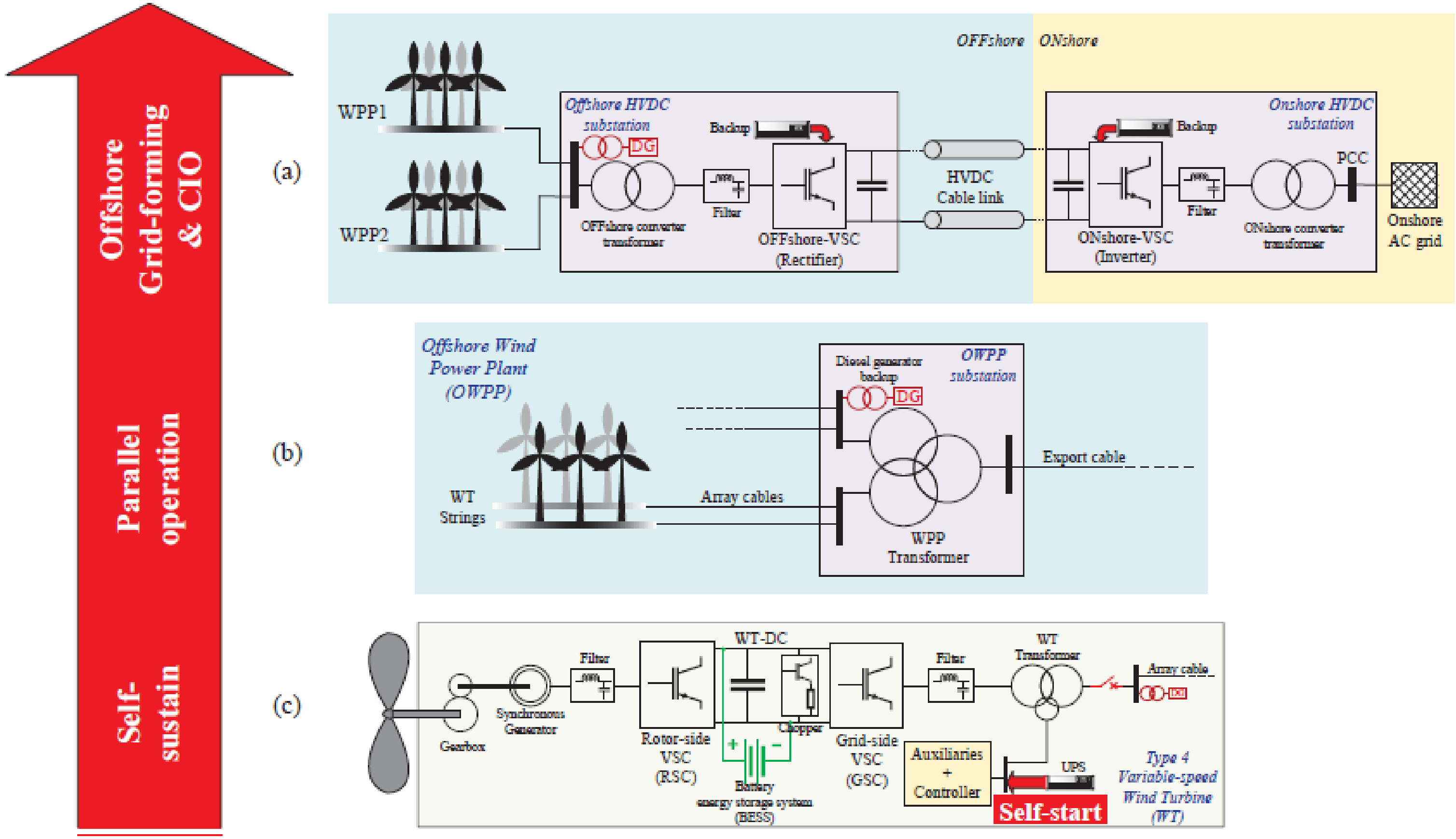
Voltage source
rather than traditional current source

WFO

No waiting for end of network reconstruction; *controlled islanding* to ensure continuity of power supply
Reduce the overall impact of a blackout event: *reduced restoration time & unserved load*
Replace *backup offshore diesel generator* for auxiliary power & energization
Cost benefits, reduced shipping downtime, increased reliability & CO2 displacement.

Poster – Blackstart & Islanding Capabilities of HVDC connected Offshore wind power plants
Anubhav Jain, J.N. Sakamuri, N. A. Cutululis, EERA JP Wind & SETWind Annual Event 2020

WPPs greenstart capability



Control Solutions for Blackstart Capability and Islanding operation of Offshore wind power plants
Anubhav Jain, K. Das, O. Gosku, N.A. Cutululis, Proc. 17th Wind Integration Workshop 2018

Reflections

- Wind power plants can deliver basic ancillary services and replace conventional power plants

- Wind power plants are capable of providing:
  - active power control
  - frequency control support
  - reactive power control
  - voltage control support

- Wind power plants **can provide** enhanced **ancillary services** – emulating synchronous generator (i.e. TFR, POD, black start)

- **Co-ordination** of wind power plants to provide ancillary services - major challenge with high share of renewables

Thank you for your attention!