Control

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Control and design for modular multilevel converters (MMC)

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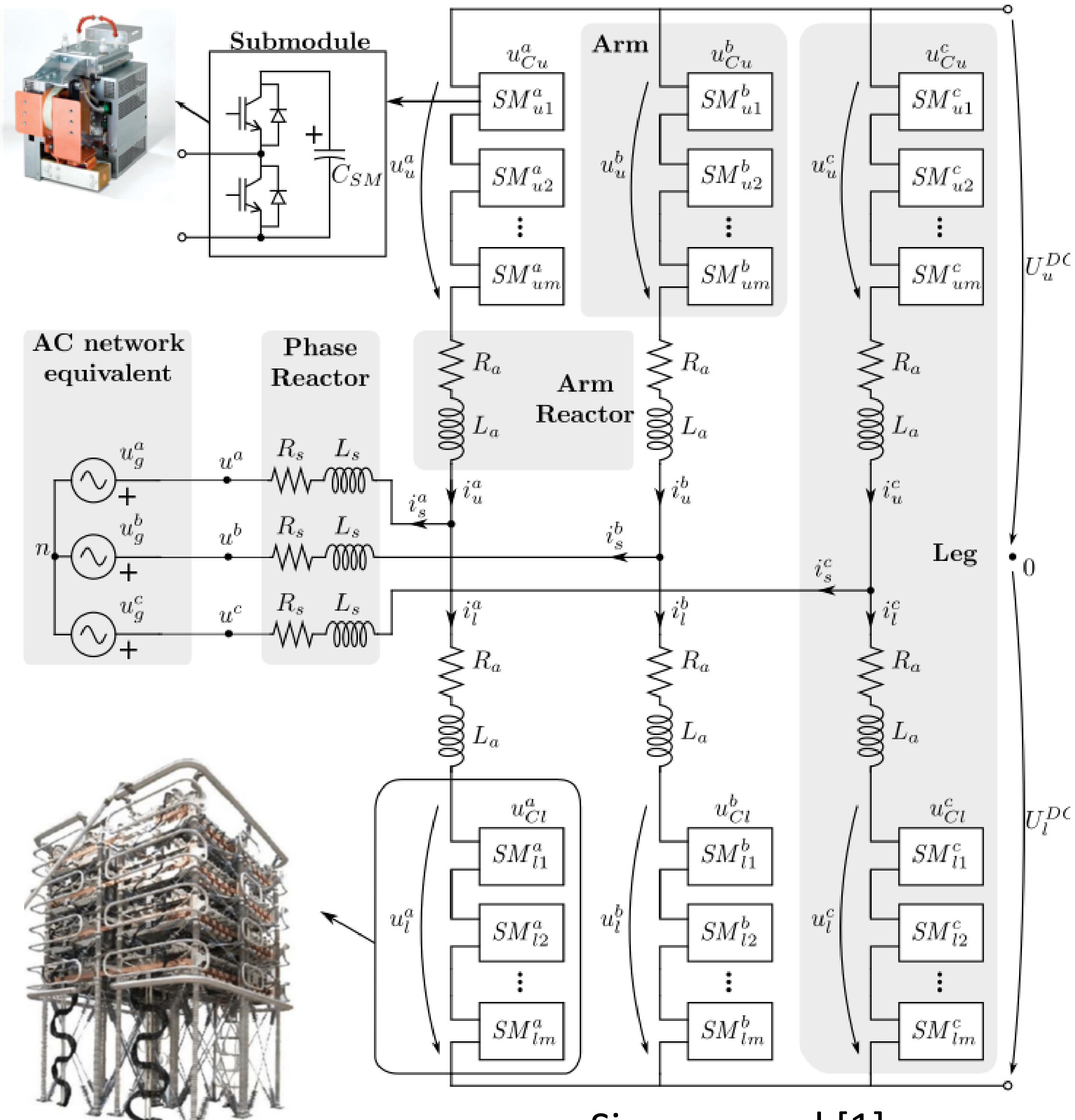
INNOVATIVE TOOLS FOR OFFSHORE WIND AND DC GRIDS

VSC-MMC

- Active and reactive powers can be controlled independently
- “Black-start ” capability
- More difficult to control

Characteristics

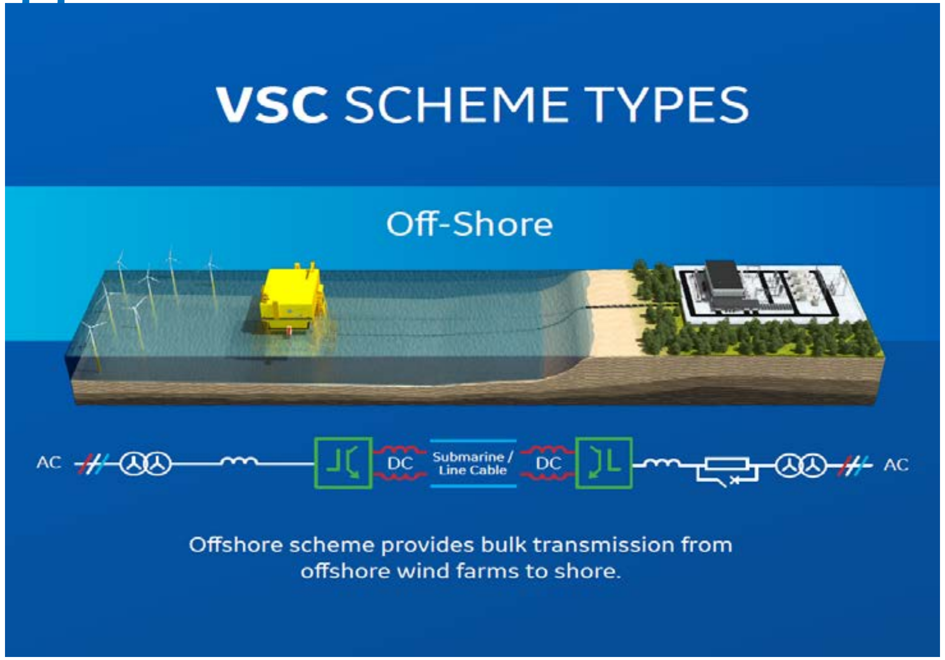
- The MMC has three legs (one per phase)
- The legs have two arms (named upper and lower arms)
- Each arm consists of N sub-modules that can be connected in series and can be turned *on* and *off* to synthesize a desired voltage level
- The arms can be controlled independently
- The energy is stored in the arms of the converter



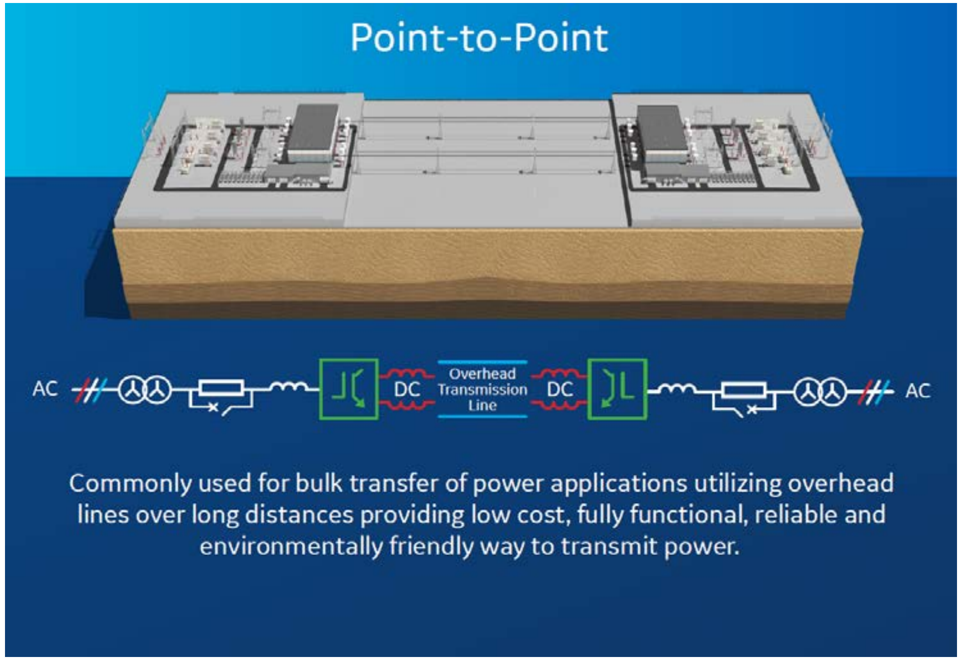
source: Siemens and [1]

[1] D. Westerman Spier, E. Prieto-Araujo, J. Lopez-Mestre and O. Gomis-Bellmunt, "Optimal current reference calculation for MMCs considering converter limitations," in IEEE Transactions on Power Delivery, doi: 10.1109/TPWRD.2020.3020420.

Applications



source: GEGridSolutions.com/HVDC



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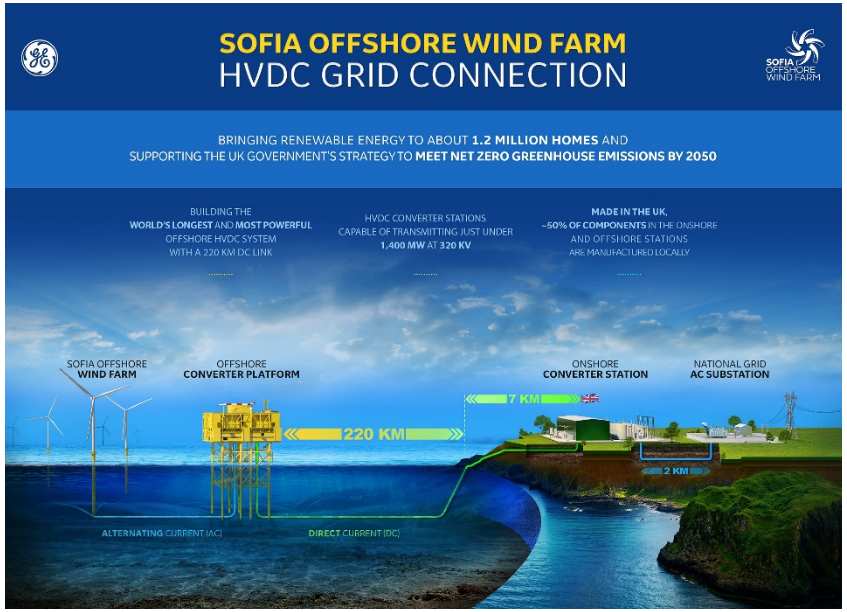
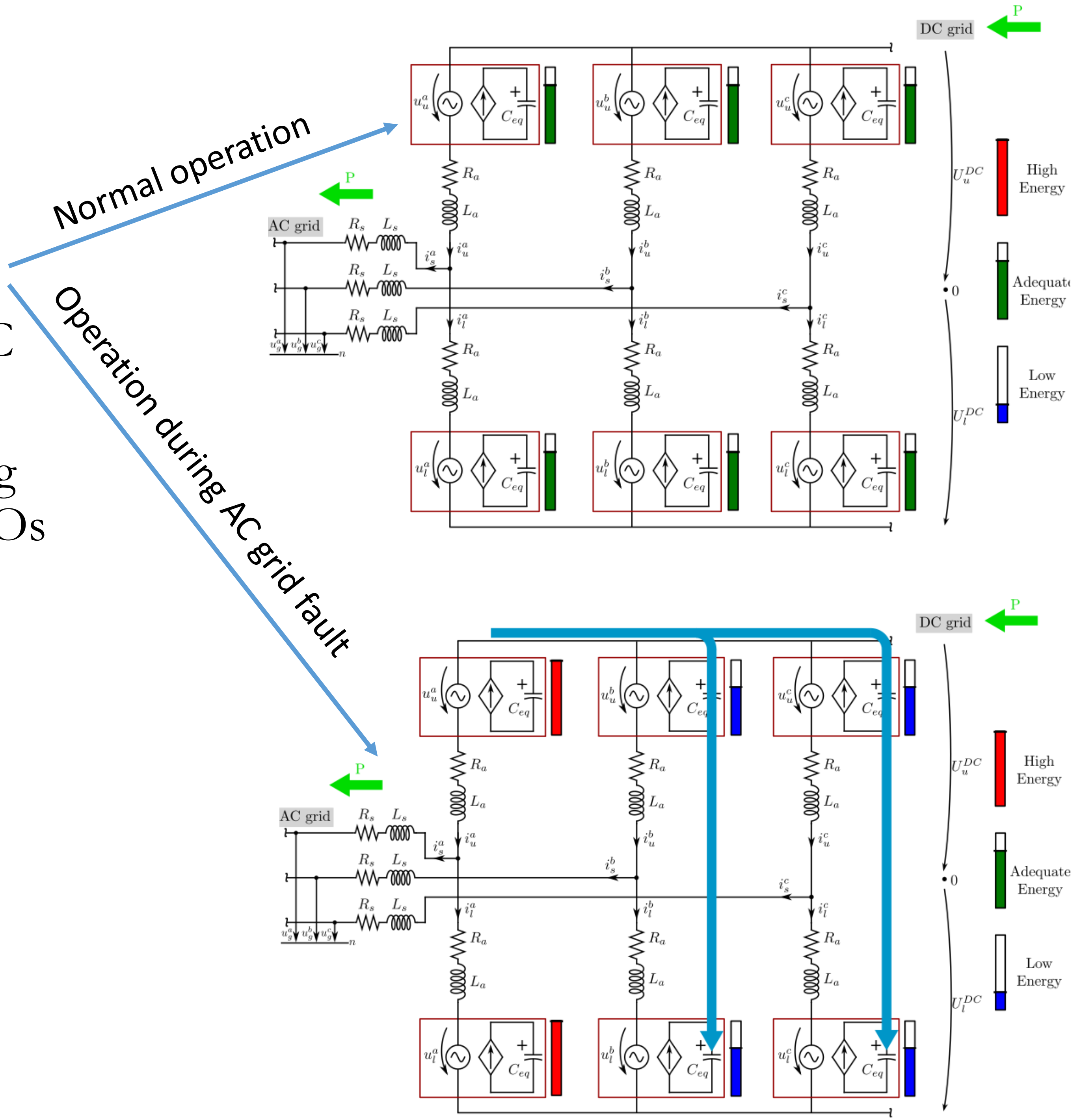


source: GEGridSolutions.com/HVDC

source: siemens and sunwindenergy.com copyright: siemens and Tafyr

Challenges

- ➢Understand the working principle of the converter
- ➢Exploit all its degrees of freedom
- ➢Maintain the internal energy of the MMC balanced
- ➢Optimize the control performance during unbalanced voltage sags (meeting the TSOs requirements)
- ➢Optimize design of the components (specially the SM capacitors) in order to reduce the weight of the structure



My contributions

- Mathematical steady-state model
- Reference calculation to be used in the controllers
- Optimize the converter performance under unbalanced AC grid voltage sags (in accordance to the TSOs requirements)

Design of advanced system controllers in HVDC grids

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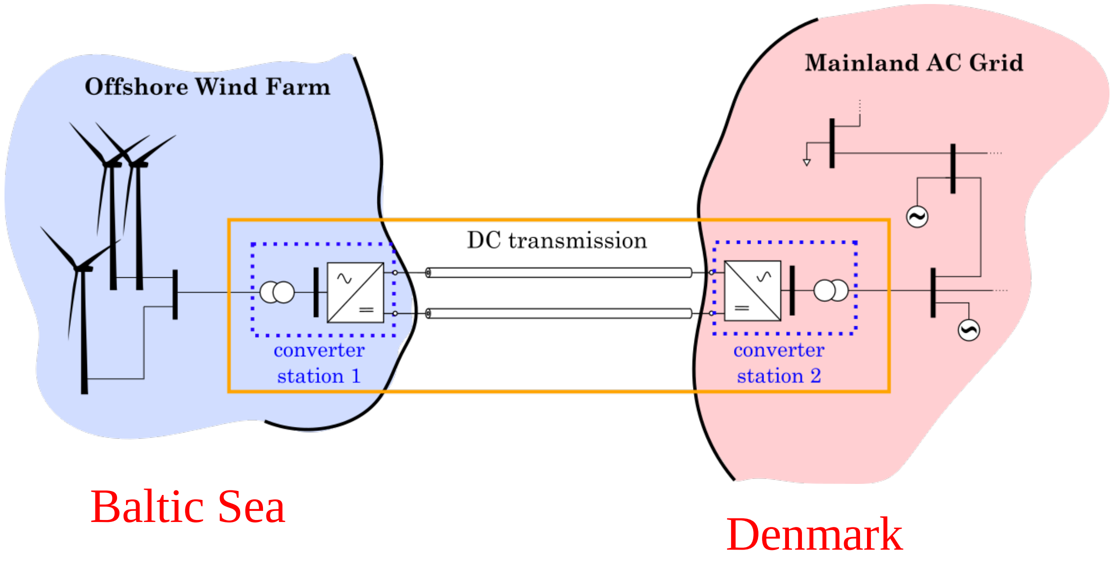
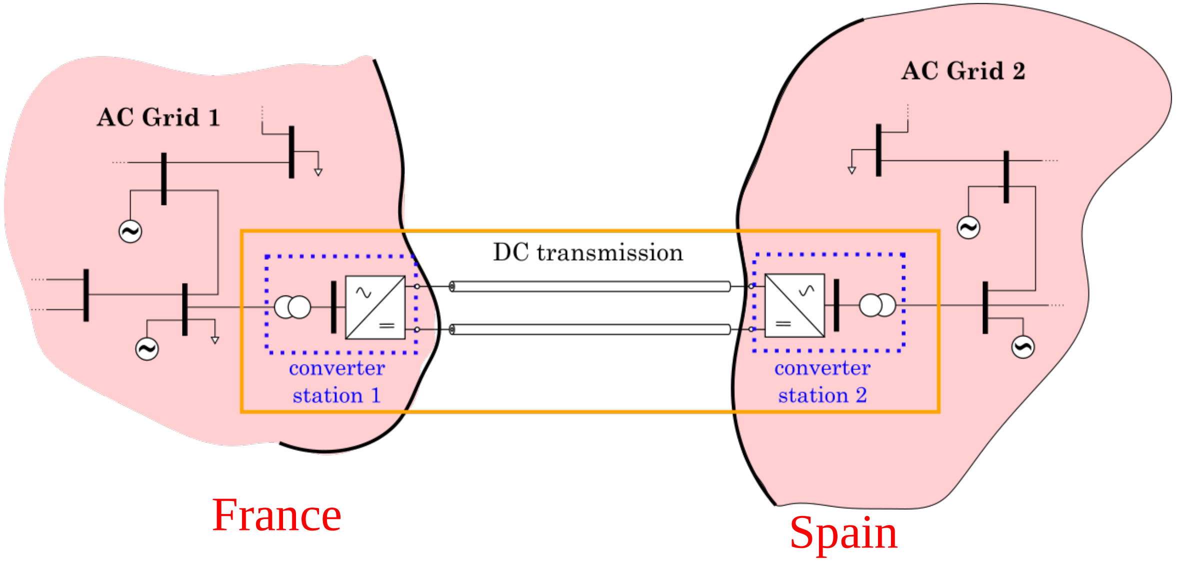
Common applications of HVDC point-to-point system



Transporting offshore wind power to the mainland AC grid



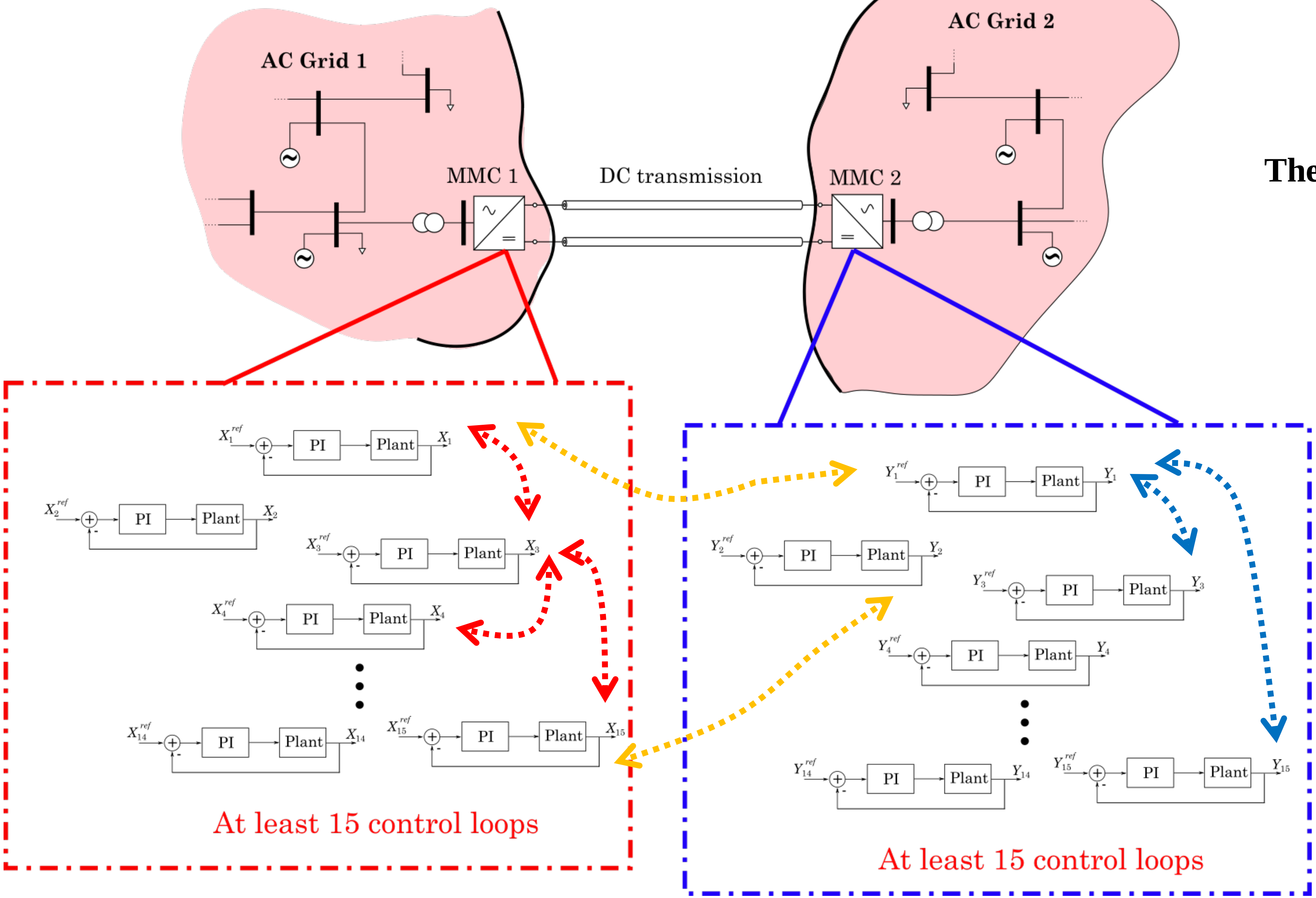
Interconnection of the AC grids of two countries

The challenges of control design for the converters 1 and 2:

1. High level of interactions between control loops
2. Parameter Uncertainties

INNOVATIVE TOOLS FOR OFFSHORE WIND AND DC GRIDS

1. High level of interactions between control loops



There exist interactions:

- inside the control system of MMCs
- and between MMCs.

A locally optimized control loop may result in the degraded overall performance of the system

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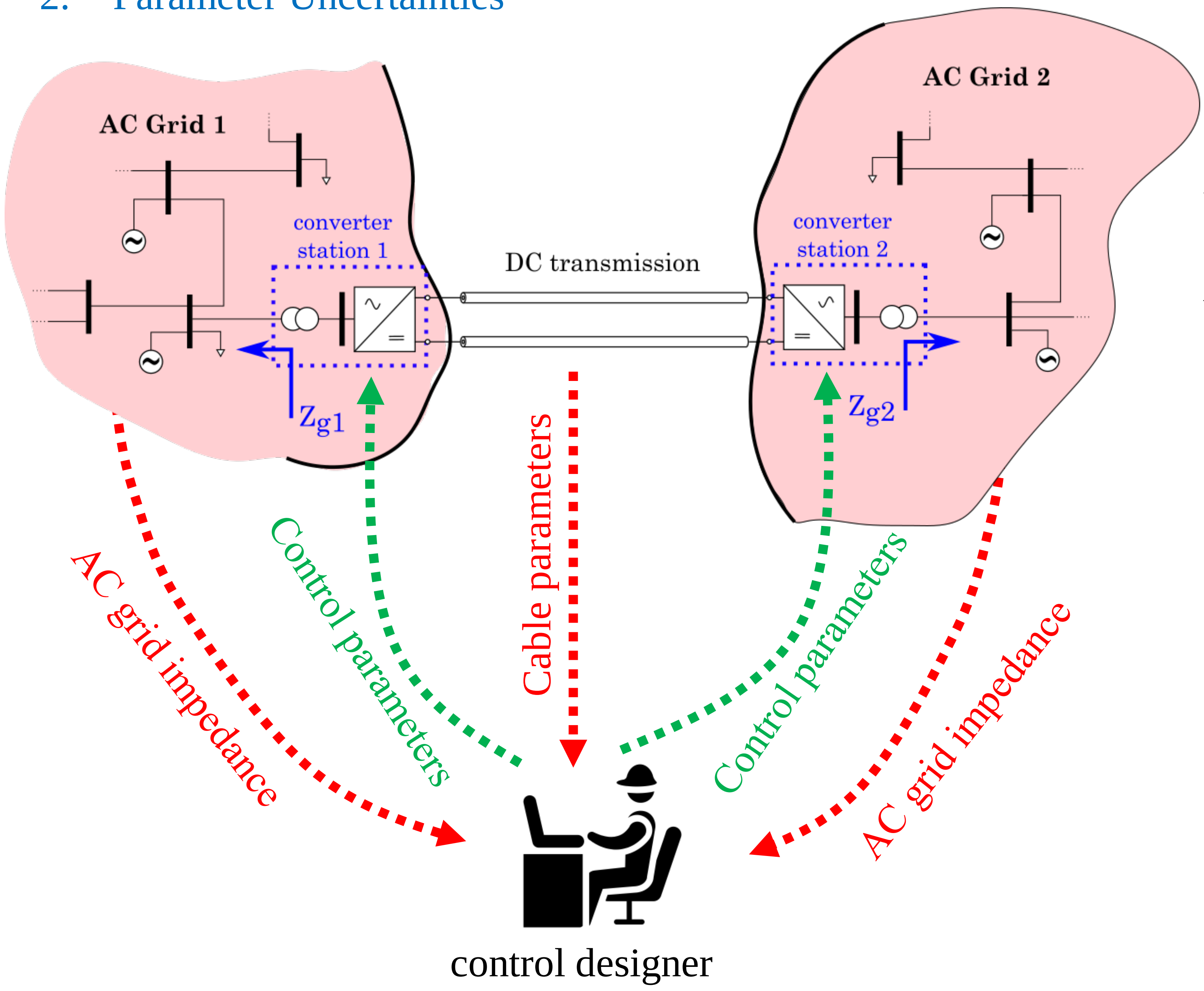
2. Parameter Uncertainties



AC grid impedances Z_{g1} and Z_{g2} have major impact on the performance of HVDC system, but their values are changing due to:

- Time-varying topology of AC grid
- Unpredictable load response
- Future expansion
- Integration of renewable energy sources

Thus, AC grids impedances Z_{g1} and Z_{g2} are uncertain parameters for control design

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Possible Solution

1. High level of interactions between control loops

Optimal design: move from SISO design to MIMO design

Global optimization that ensures the best performance obtained for all control loops

- Optimal H_2 Design
- Optimal H_∞ Design

2. Parameter Uncertainties

Robust design: move from operating point design to a design based on the uncertainties

Guaranteed stability and performance for all grid impedance variations

- Robust μ Design

Black start and islanding operation capabilities of offshore wind power plants

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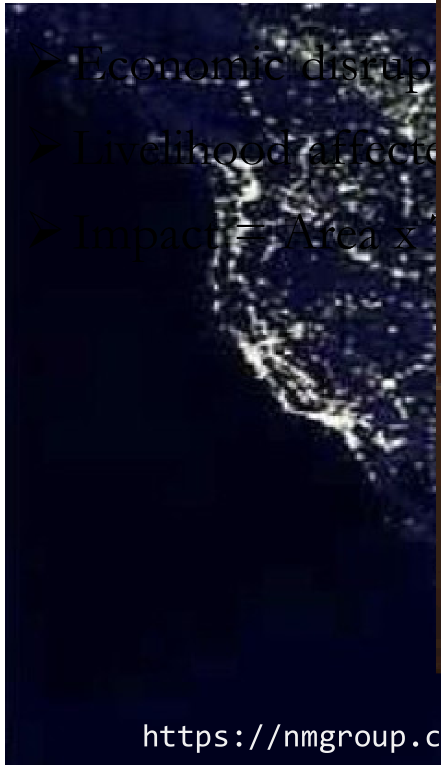
Blackout is a HILF

- Economic disrup
- Livelihood affecte
- Impact = Area x



Largest [edit]

Article	People affected (millions)	Location	Date	References
2012 India blackouts	620	India	July 30–31, 2012	[1][2][3]
2001 India blackout	230			
			May 21, 2002	
2019 Venezuelan blackouts	30	Venezuel		

https://en.wikipedia.org/wiki/List_of_major_power_outages

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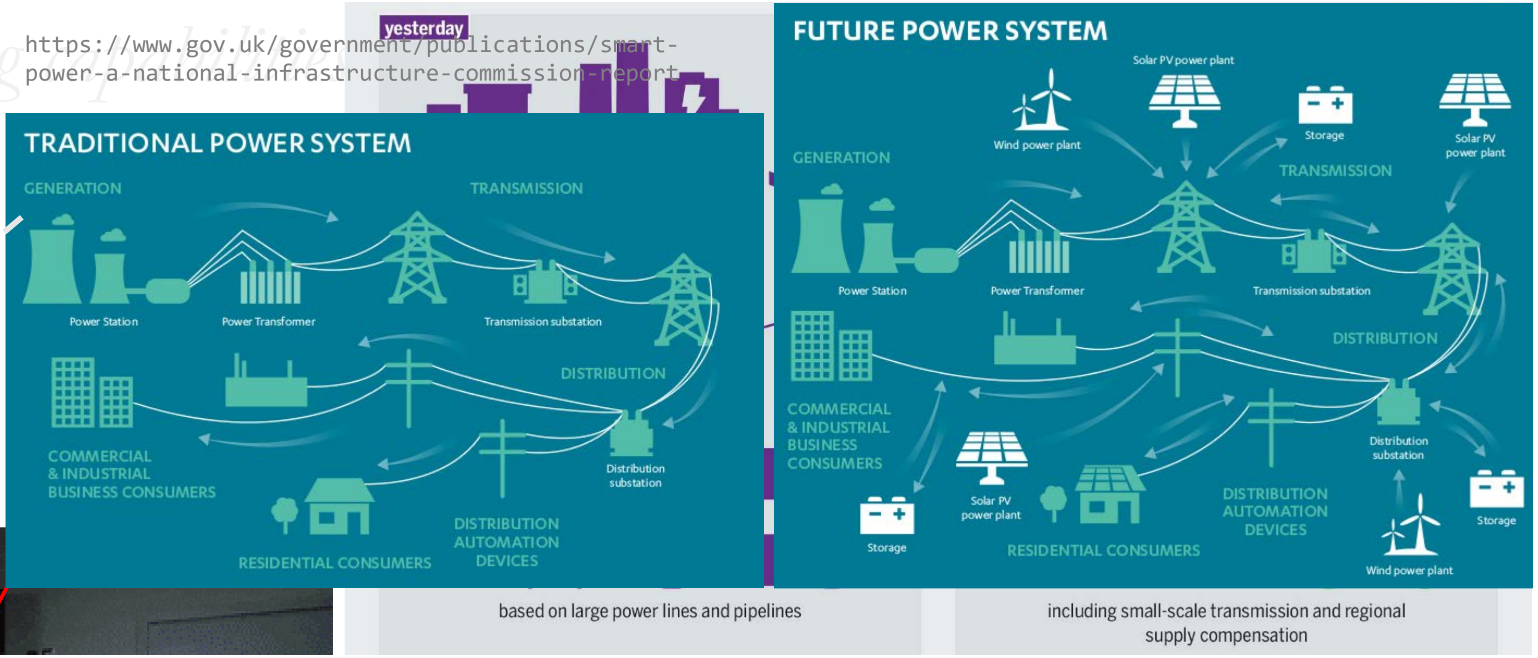
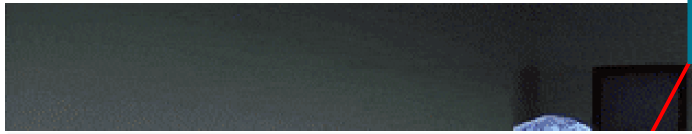
Blackstart & Islanding capabilities

https://www.gov.uk/government/publications/smart-power-a-national-infrastructure-commission-report

Blackstart Unit

- ➢ Pumped-hydro storage
- ➢ Gas-fired generators
- ➢ Wind power plants ?





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.

Blacked out grid

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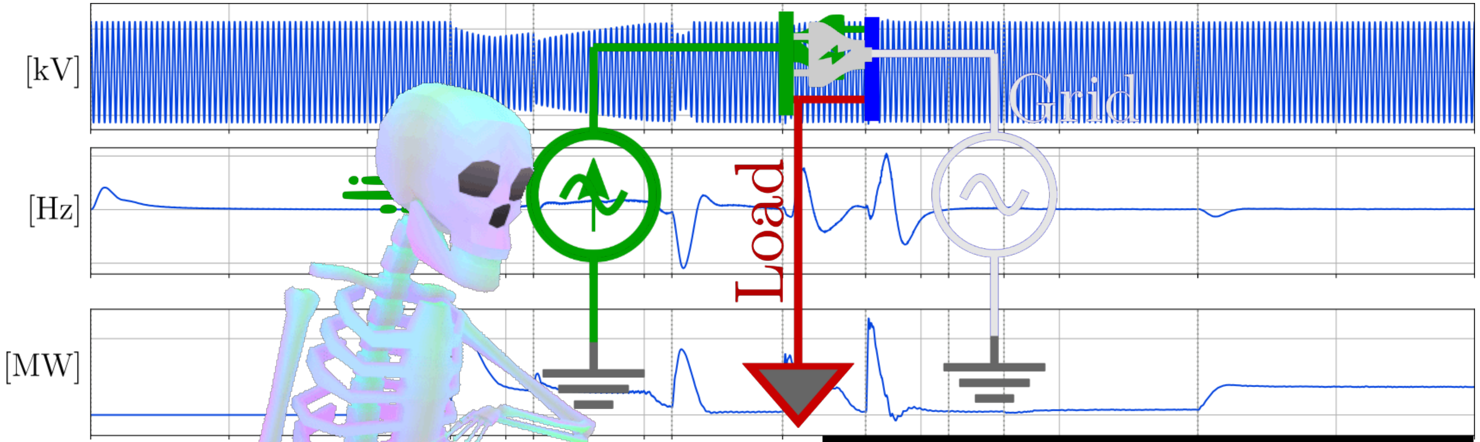
Blackstart & Islanding capabilities of Offshore wind power plants

Challenges

- ➢ Demanding transients
- ➢ Control: GFL → GFM
- ➢ Stability & Safety
- ➢ Market: €/MW



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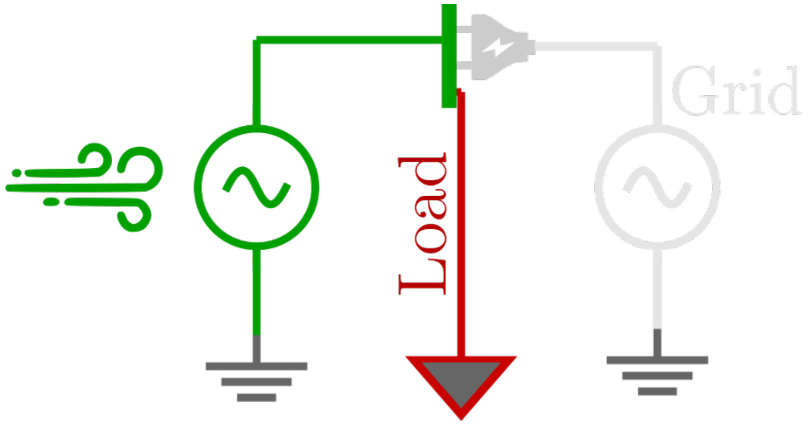
Blackstart & Islanding capabilities of Offshore wind power plants

Stand-alone operation

- Independent
- Diesel generator offshore
- € savings
- CO_2 displacement



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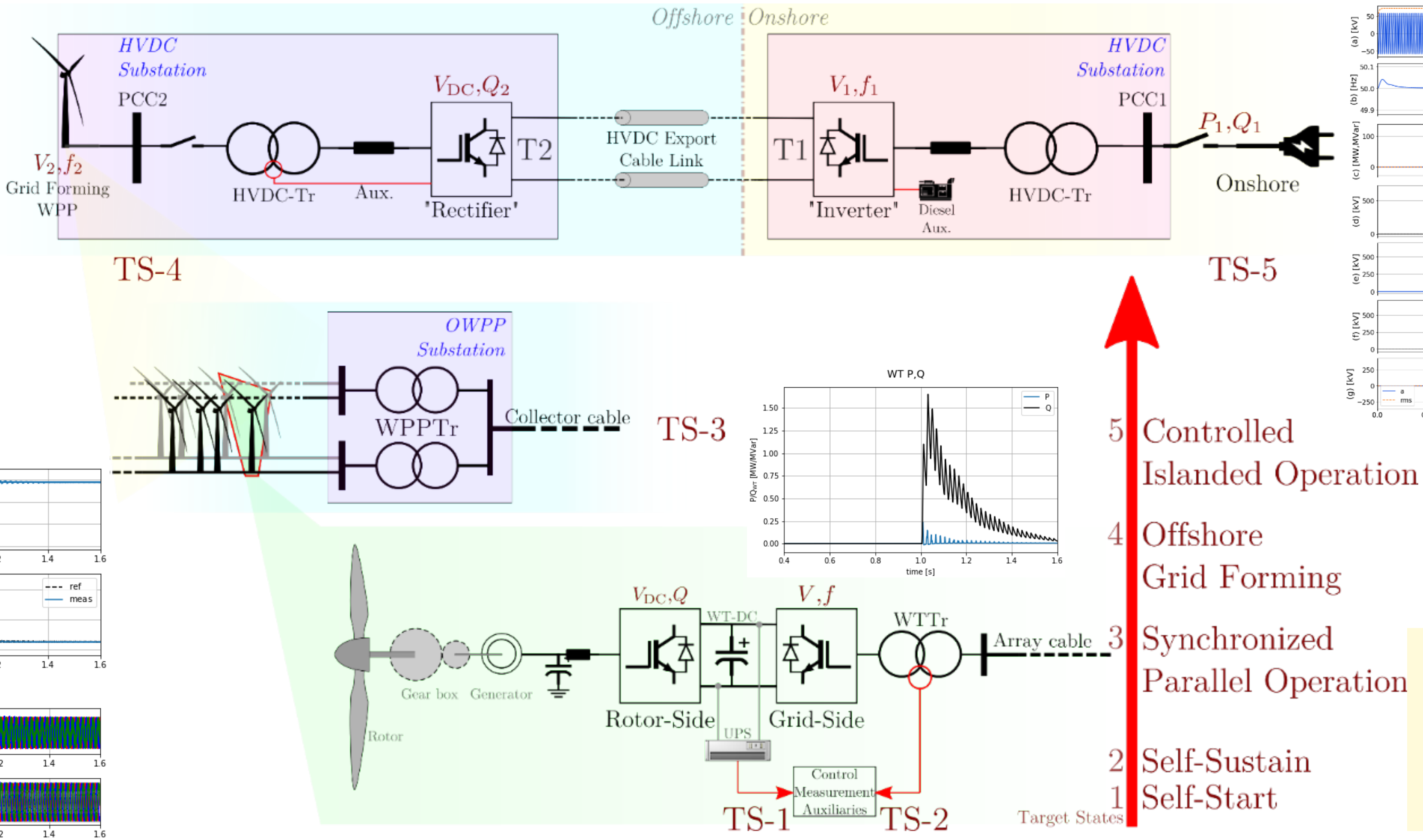

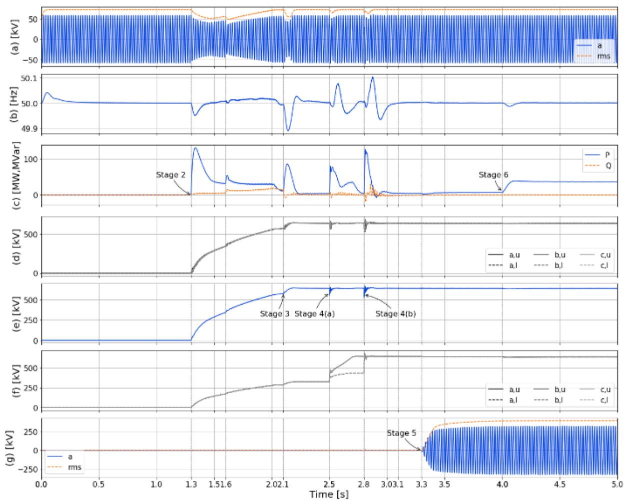

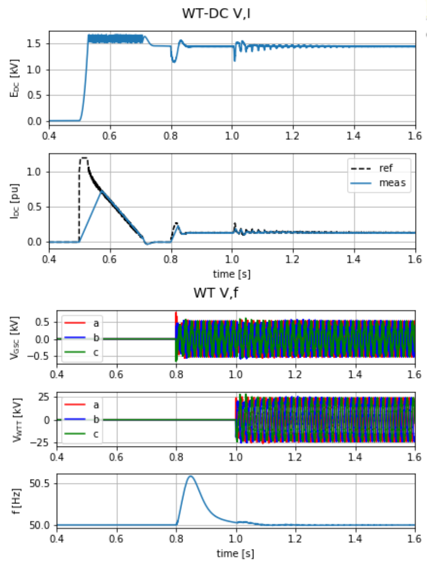

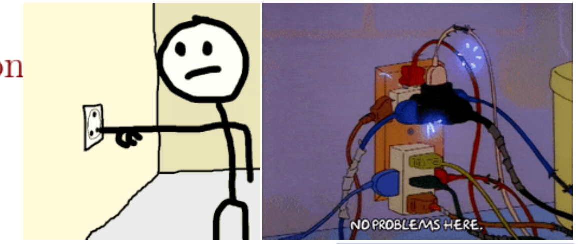

INNOVATIVE TOOLS FOR OFFSHORE WIND AND DC GRIDS

Enhancement to SCADA/EMS for hybrid AC/DC networks

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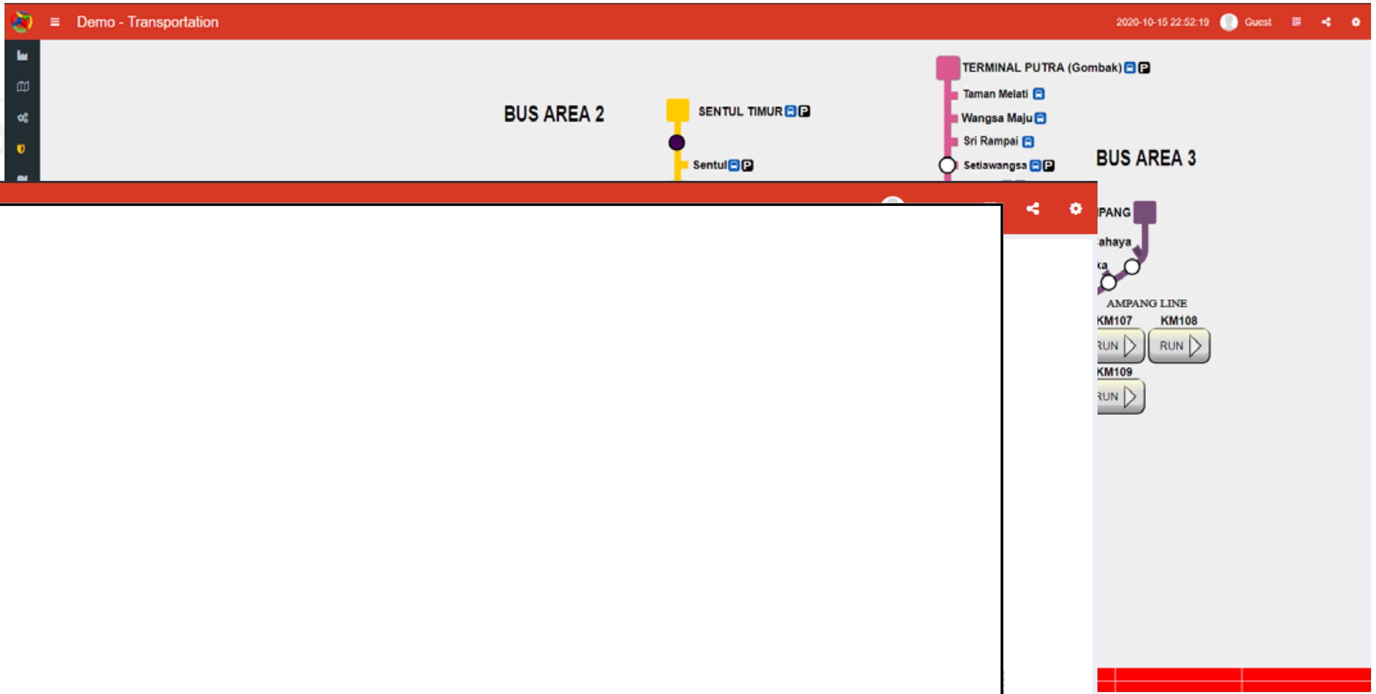
SCADA: Supervisory control and data acquisition
EMS : Energy management system

Enhancement to SCADA / EMS

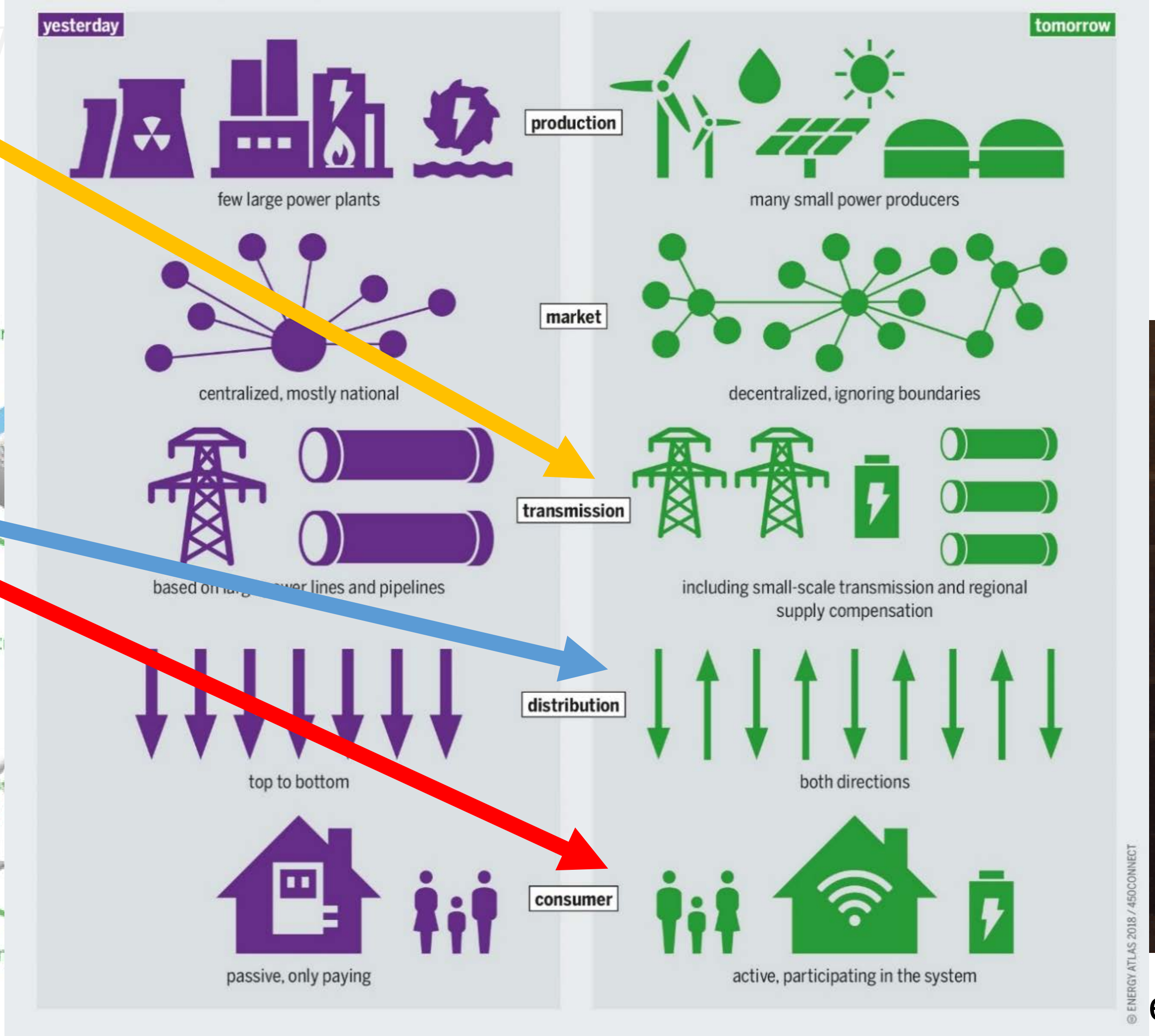


INNOVATIVE TOOLS FOR OFFSHORE WIND AND DC GRIDS

Enhancement to SCADA/ *EMS*

Introduced in the 2000s

- ➢ EMS > SCADA?!
- ➢ EMS vs (A)DMS vs DSM



Enhancement to ***SCADA/EMS*** *for hybrid AC/DC networks*

Components

- Human Machine Interface (HMI)
- Communication Infrastructure
- End-side Remote terminal Unit (RTU)

Managements and Functions (Toolboxes)

- Operations Management
- Outage Management System
- Power Application Software (PAS)

Enhancement to *SCADA/EMS for hybrid AC/DC networks*

Challenges

- Unified HMI and toolboxes
- New RTUs characteristics
- Advanced protection requirements
- Timescales requirements
- Big Data and communication infrastruc
- Global variables
- Cybersecurity

INNOVATIVE TOOLS FOR OFFSHORE WIND AND DC GRIDS

Enhancement to ***SCADA/EMS*** *for hybrid AC/DC networks*

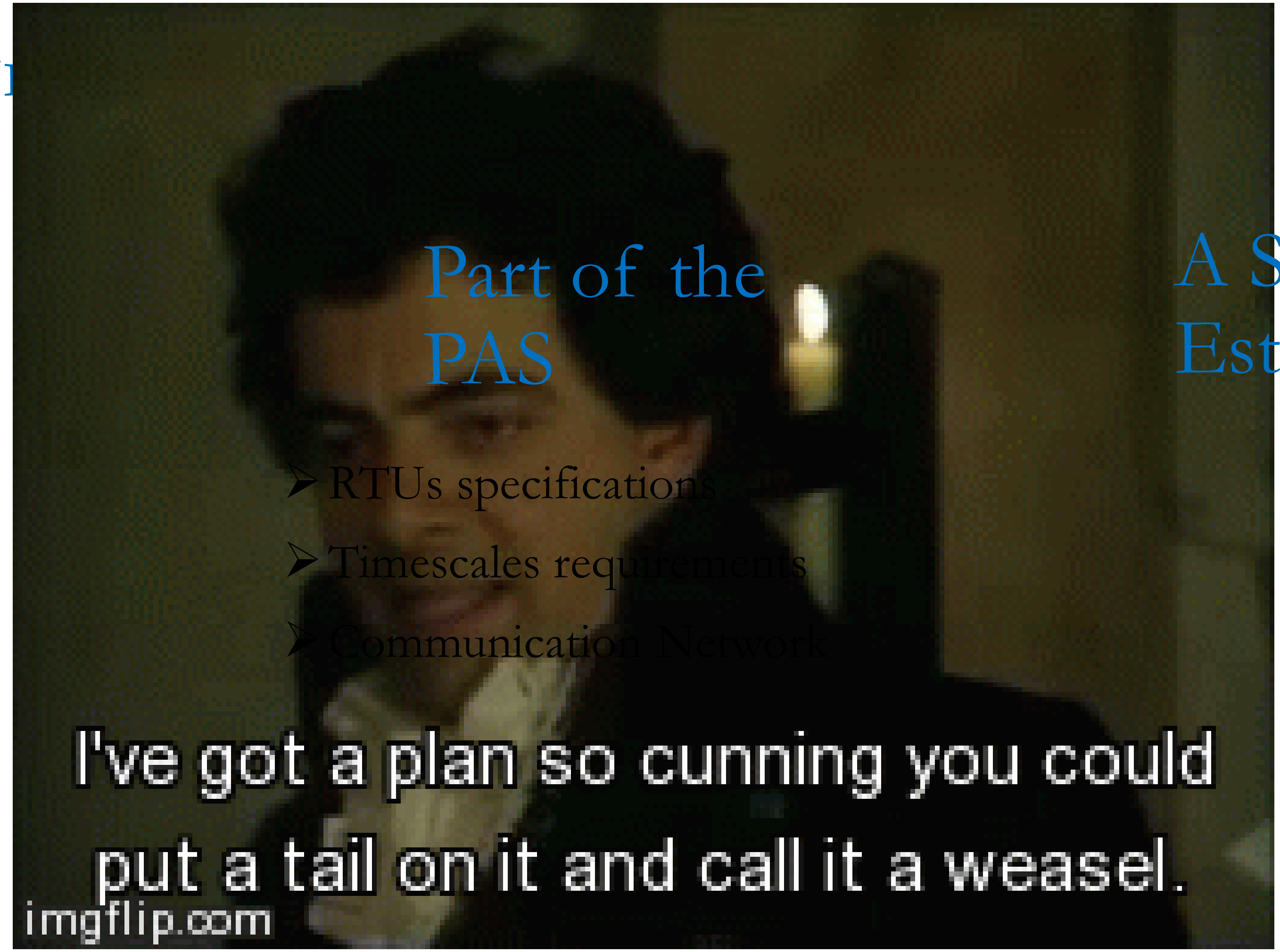
My Contribution/I

Unified toolbox

Part of the PAS

- RTUs specifications
- Timescales requirements
- Communication Network

A State Estimator



Src: Blackadder

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Thanks for your attention

Questions?