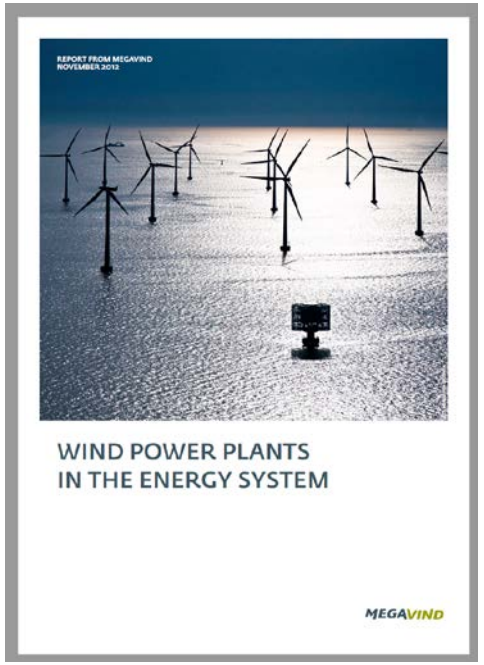
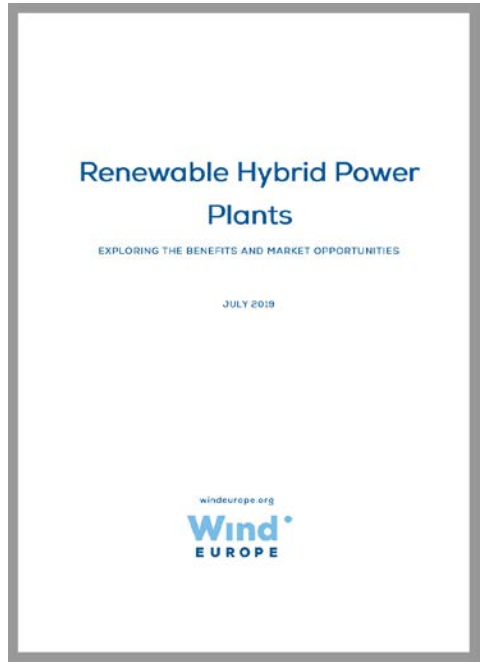
Research at DTU Wind
Hybrid Wind Power Plants

Kaushik Das
URC Grid Integration and Hybrid Power Plants
20.12.2021

From wind turbines to wind power plants to hybrid power plants – system integration agenda





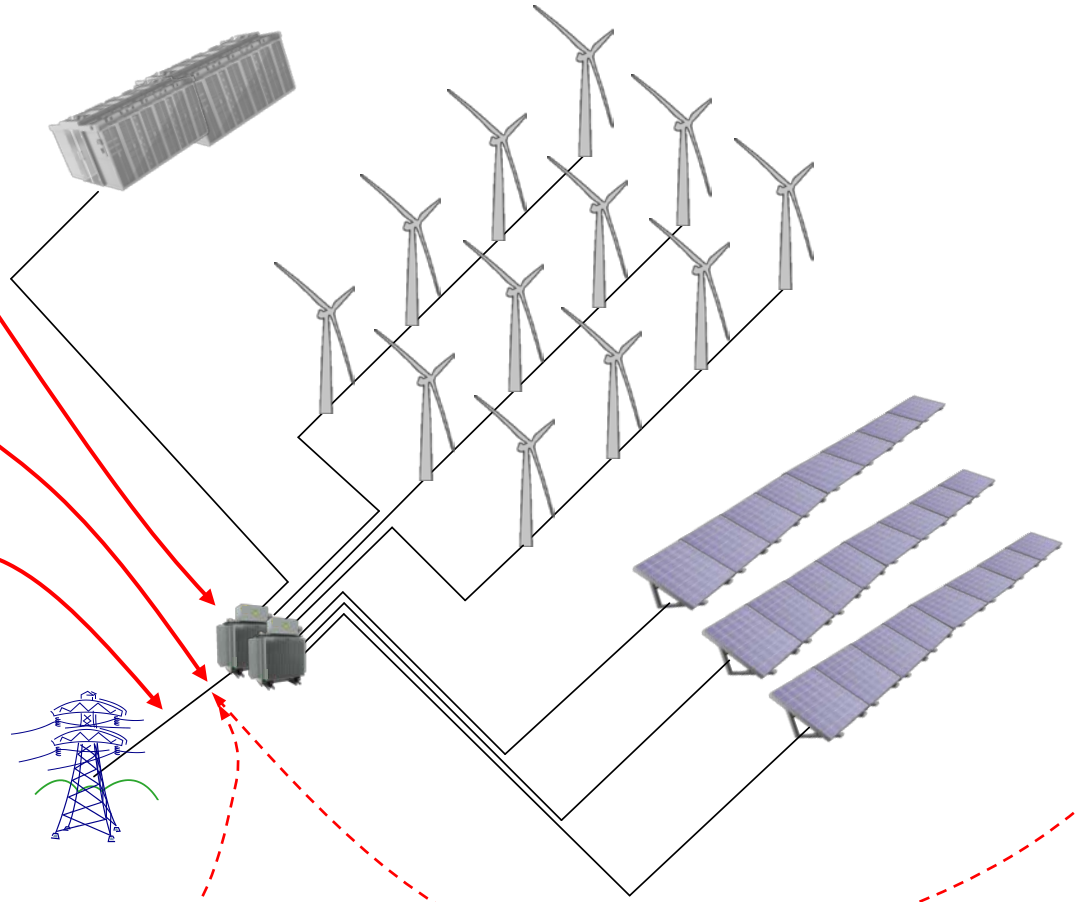
Hybrid Wind Power Plants

- HWPP – Hybrid Wind Power Plants
  - Wind Power +/ Other RES +/ Storage(s)
  - with common AC point of connection typically connected to MV or HV grid
    - AC or DC or Hybrid collection system is possible
- Driver for design and operational objectives is maximizing the value for owner
  - Market based services
  - Grid code requirements
- Shared land allowing for physical interaction between technologies
- Sector-coupled with other energy productions especially Wind+H2 systems is also included

General Features:

- All the assets are owned by same company so higher controllability
- Motivation is to maximize profit from different energy markets
- Control of electrical load is not of concern of the power plant owner as compared to traditional Hybrid Power Systems
  - Sometime even provide near baseload generation
- Many stakeholders involved

Hybrid power plant – unmet needs and challenges



Cost of electrical infrastructure

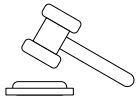
Connection requirements

Grid capacity and utilization

Ancillary services capability

Control centre

Forecasts



Electricity markets

Increase value of renewable generation

1. Energy markets
2. Ancillary services

HPP Projects

Danish HPP Forum Established

Indo-Danish IFD HYBRIDize

Christian og Anny Wendelbo's Fond

Daniel Pombo starts

MSCA ITN - WinGrid

Rujie Zh[illegible]arts PhD

EUDP HybridStorage

IEA Wind Task 50 – HPP Approved

EUDP IEA Wind Task 50 Danish Consortium

DTU HWPP Facility Phase 1

Total Co-sponsored Project

Charbel starts PhD

3 PhDs to start

MT, Alex Vestas

MT, Joaquin

MT, Filippos

MT, Swarnima

MT, Giorgos

MT, Alessandra *Suzlon*

MT, Aivaras *Vestas*

MT, Pablo *Vattenfall*

OMP, Sebastien *Ørsted*

2019 | 2020 | 2021 | 2022

MT, Anatole *Suzlon*

MT, Xenofon *Suzlon*

MT, Panagiota *Suzlon*

MT, Johannes

MT, Anton

OMP, Emilio *Stiesdal*

MT, Mathias *Vattenfall*

MT, Jaber

MT, Shree

MT, Sam *DTU Energy, Haldar Topsøe*

CAMIN Consultancy Project

MT, Claudia

DTU-UQ collaboration *Fatemeh starts Ph[illegible]*

EUDP REALISE

MT, Kasper

- MT/OMP – Master Thesis/Online Master Project
- Project
- Outreach
- Lab

All publications are in Danish Hybrid Power Plant Forum website - https://files.dtu.dk/userportal/?v=4.5.0#/shared/public/_Pn4RJr5-Azu-fhE/HPP%20DTU%20Publications

DTU Wind Energy
Department of Wind Energy

SUZLON
POWERING A GREENER TOMORROW

Hybrid Greentech

नीवे NIWE

DTU Wind Energy

भारतीय प्रौद्योगिकी संस्थान खड़गपुर
Indian Institute of Technology Kharagpur

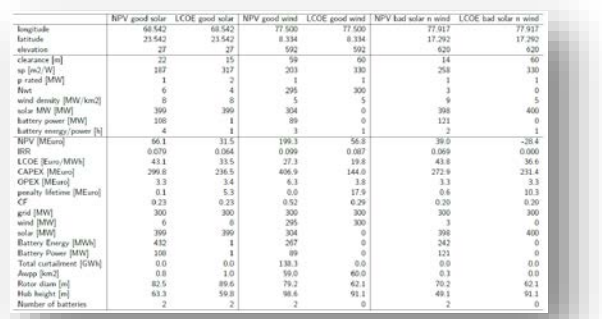
HYBRIDize

Objective:

- minimize levelized cost of energy (LCOE) and levelized cost of storage (LCOS)
- maximize profit for HPP

Main Outcomes from DTU:

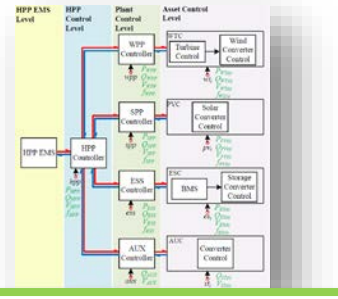
Sizing



Hybrid plant sizing for wind, photo-voltaic and Lithium-ion battery storage

Juan Pablo Murcia[1], Kaushik Das[1], Rujie Zhu[1]

Supervisory Control



Optimal battery operation for revenue maximization of wind-storage hybrid power plant

Kaushik Das, Anatole Louis Theodore Philippe Grapperon, Poul E. Sørensen, Anca D. Hansen

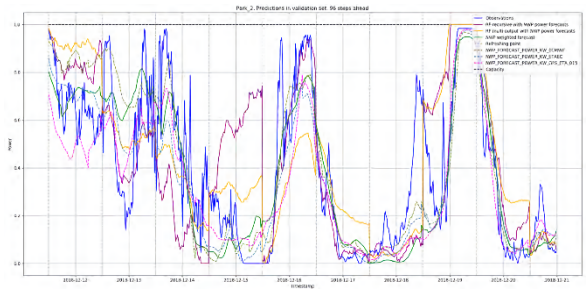
Hierarchical Control Architecture of Co-located Hybrid Power Plants

Qian Long, *Member, IEEE*, Kaushik Das, *Senior Member, IEEE*, and Poul Sørensen, *Fellow, IEEE*

European and Indian Grid Codes for Utility Scale Hybrid Power Plants

by Anca Daniela Hansen, Kaushik Das, Poul Sørensen, Pukhraj Singh and Andrea Gavrilovic

Forecasting



Multi-Horizon Data-Driven Wind Power Forecast: From Nowcast to 2 Days-Ahead

Daniel Vázquez Pombo, Tuhfe Göçmen, Kaushik Das, and Poul Sørensen

Data driven probabilistic forecasting for wind-solar hybrid power plants

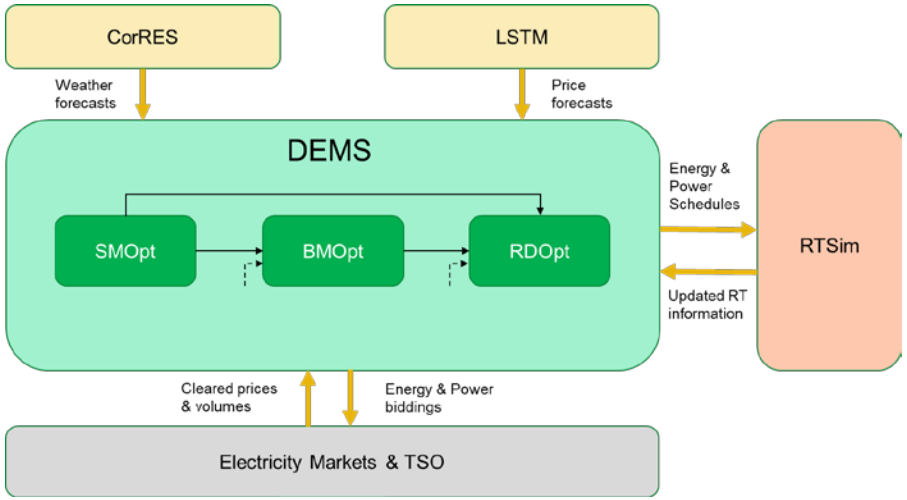
Tuhfe Göçmen, Kaushik Das, *Senior Member, IEEE*, Rangaraj A.G., Andrea Gavrilovic, Pukhraj Singh

Innovation Fund Denmark

WinGrid

Objective:

- Optimization and Control of Wind, Solar and Storage in Hybrid Power Plants in different electricity markets



Optimal Energy Management of Renewable Hybrid Power Plants in Spot Market considering Battery Degradation

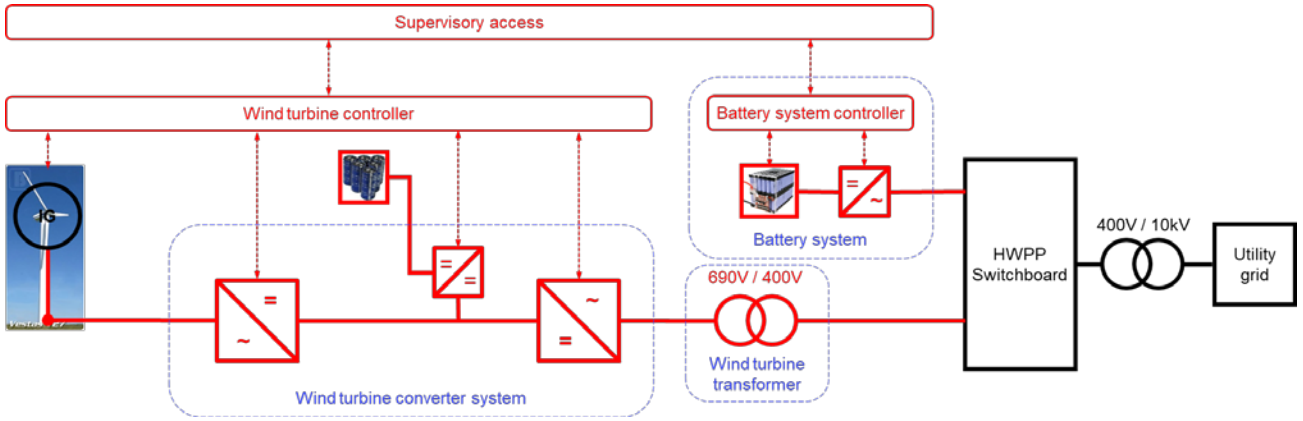
Rujie Zhu, Kaushik Das, Poul Sørensen, and Anca Hansen

Assets	Operation stratergy							k€					
		Wind			Market		Remark	SM revenue	BM revenue			Degradation Cost	Profits
		DA	HA	5min_ahead	SM	reg			regulation	imbalance	BM total		
WPP+BESS	SMOpt+ BMOpt+ RDOpt	✓	✓	✓	✓	✓	Perfect forecast	6868	580	-517	63	409	**6522**
							Real forecast	6723	131	-1007	-876	626	5221
	SMOpt+ BMOpt	✓	✓	-	✓	✓	Perfect forecast	6868	582	-513	68	410	6527
				-			Real forecast	6731	120	-1030	-910	630	5191
	SMOpt+ RDOpt	✓	-	✓	✓	✓	Perfect forecast	6783	0	-163	-163	342	6278
			-	-			Real forecast	6676	0	-899	-899	325	5452
	SMOpt	✓	-	-	✓	-	Perfect forecast	6865	0	-212	-212	579	6074
			-	-		-	Real forecast	6732	0	-994	-994	293	5445
WPP	MPPT	-	-	-	-	-	-	6597	-	-	-	-	6597

Hybrid Storage

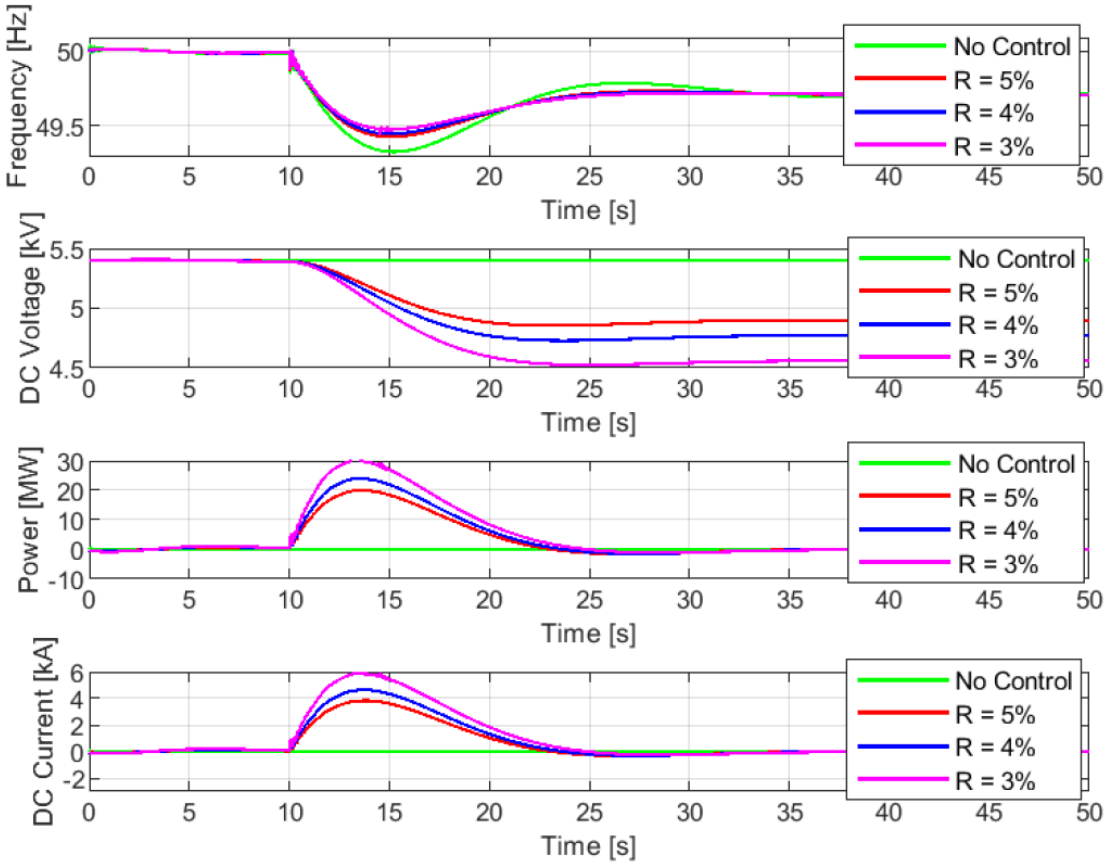
Objective:

- Frequency services from Wind Turbine with Hybrid Storage



Fast Frequency Support from Hybrid Wind Power Plants Using Supercapacitors

by Qian Long [1,*,†], Aivaras Celna [2,†], Kaushik Das [1,*] and Poul Sørensen [1]



EUDP

Projects just started

- DTU+Univ. of Queensland PhD project
  - Control of Hybrid Power Plants connected to weak grids

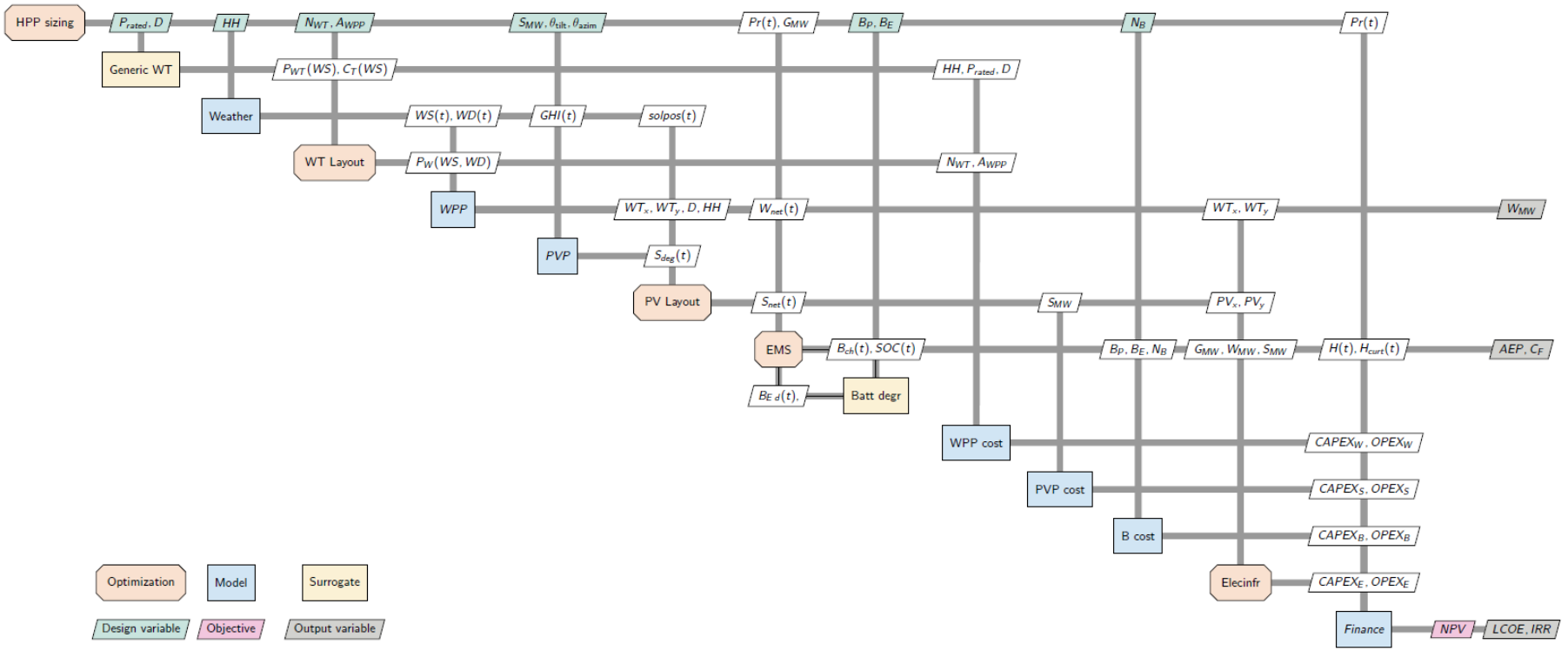
- Total funded HPP project: Focus- Design and Control of Renewable Energy Park including P2X
  - 4 PhD projects on
    - Component Sizing of HPP
    - Physical Design of HPP
    - Electrical Design and control of HPP
    - Energy management system and control of HPP

- REALISE
  - Design tool for renewable energy parks based on HyDesign, Balancing Tool Chain, CorRES, TopFarm

HyDesign

Design tool for Hybrid Wind Power plants

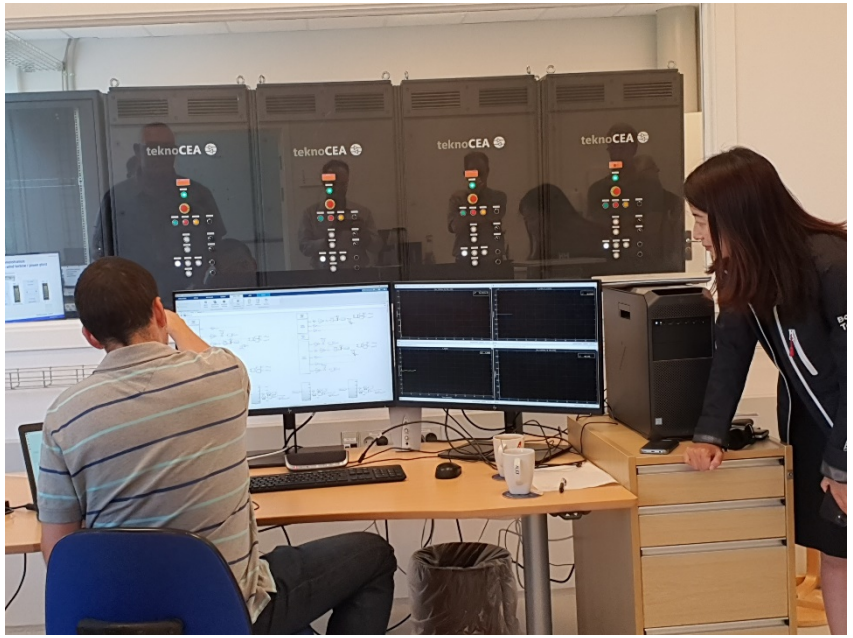
Developed in OpenMDAO platform



Sizing of components	Physical Design
Grid Codes	Energy Management System
Balancing Tool Chain	Interactions
Power2X	Forecasts
Reliability	Electrical system Design

AC/DC WindPowerLab: Converter-based laboratory

- 4 x 10 kW voltage source converters (VSCs):
  - 2 two-level converters (2LCs)
  - 2 modular multilevel converters



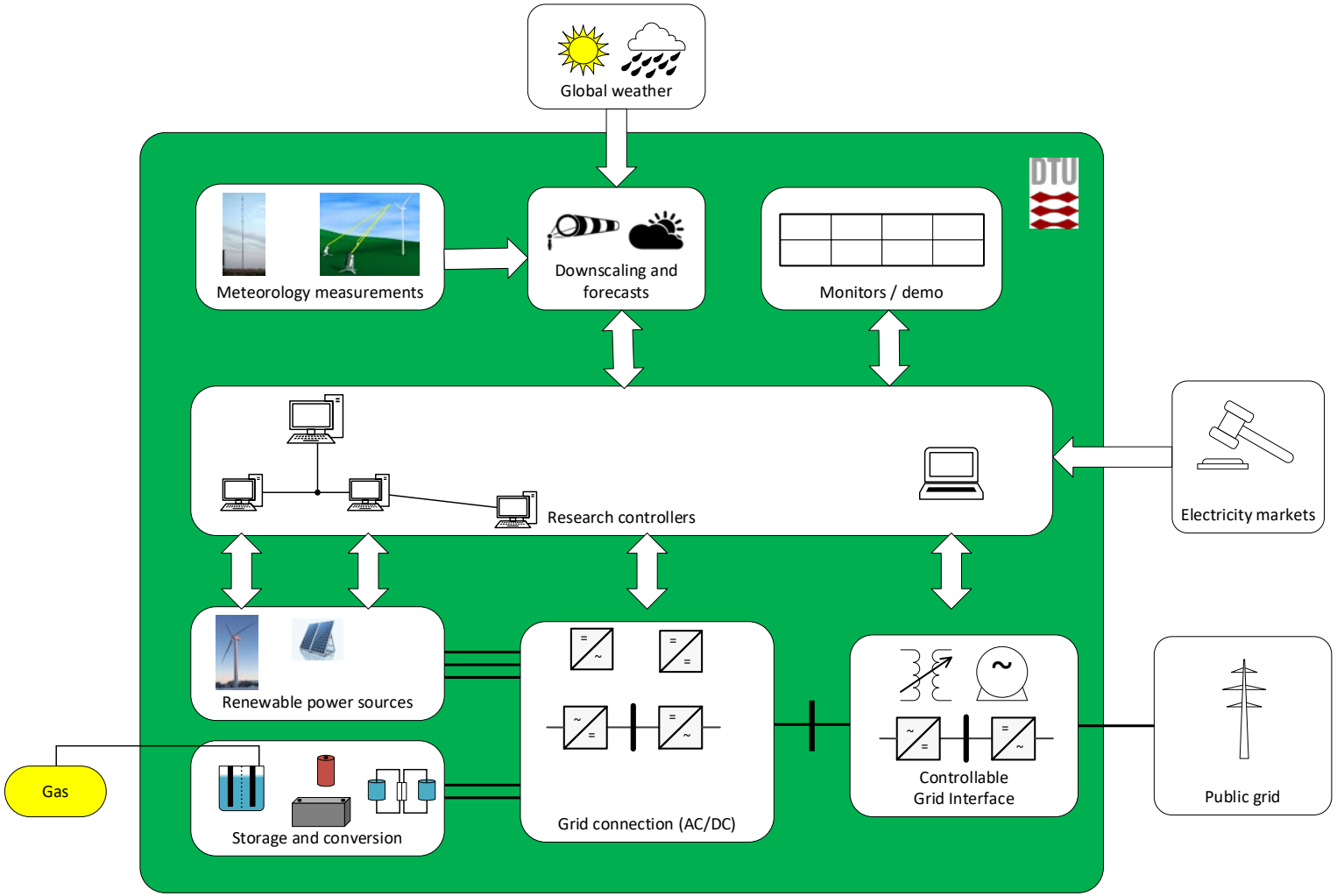
speedgoat
real-time simulation and testing

teknoCEA

UPC

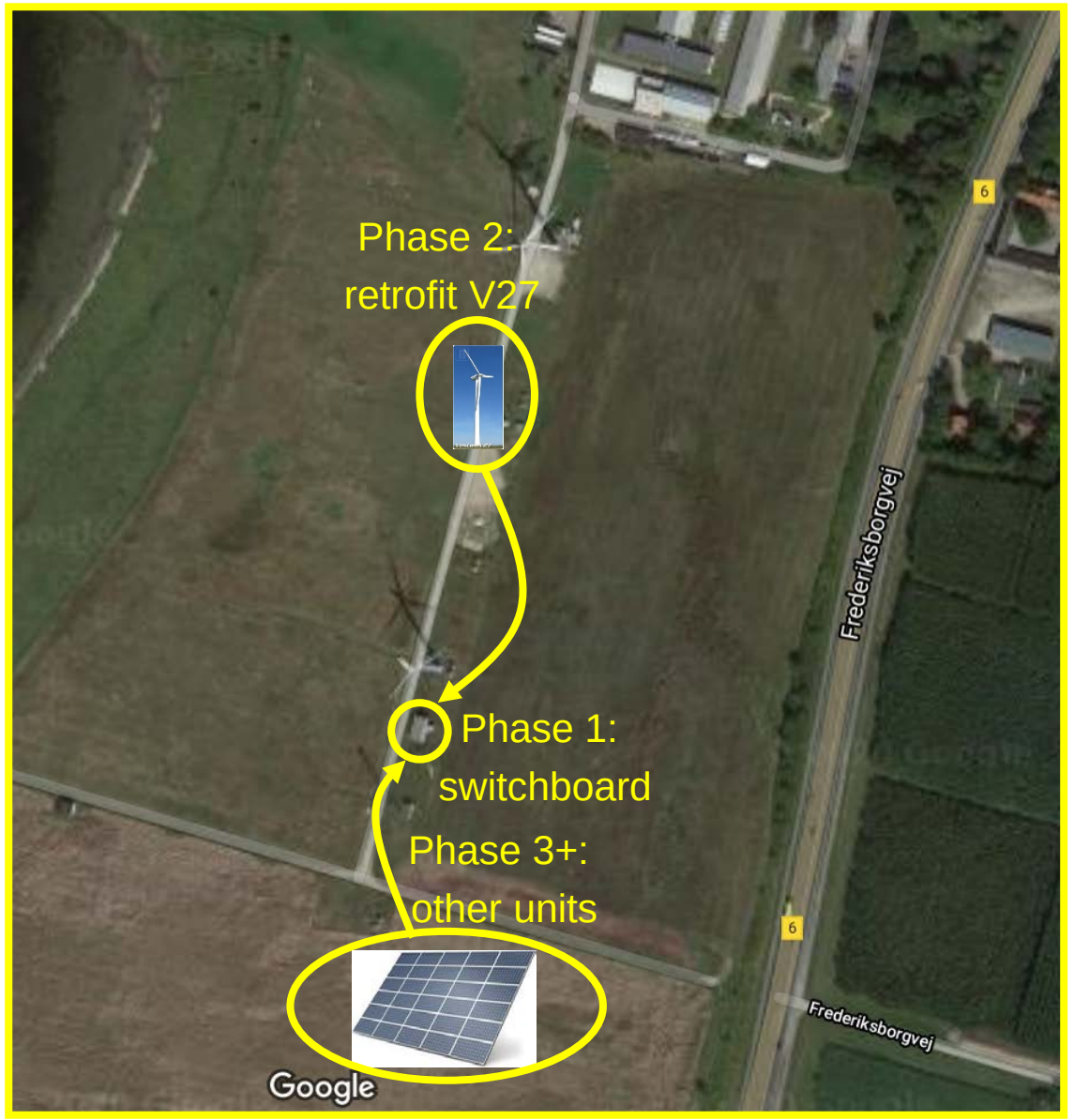
DTU Wind Hybrid Power Plant Facility – vision

- Grid connected wind-hybrid power plant (wind / solar / storage)
- Open research controllers
- Power collection and gird connection (AC / DC)
- Controllable grid interface
- Connection to external information (weather forecasts, markets)

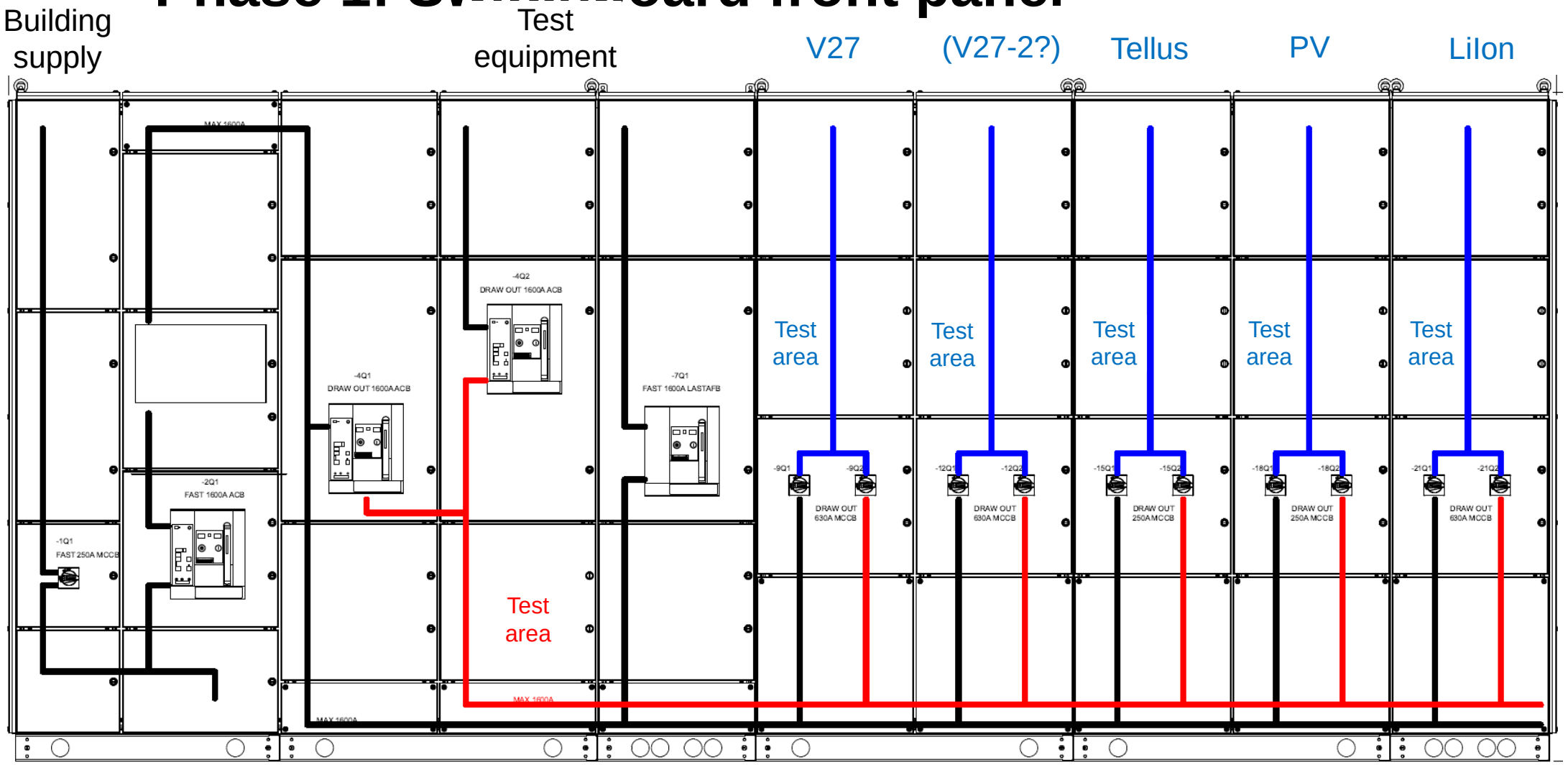


Hybrid Wind Power Plant (HWPP) Facility

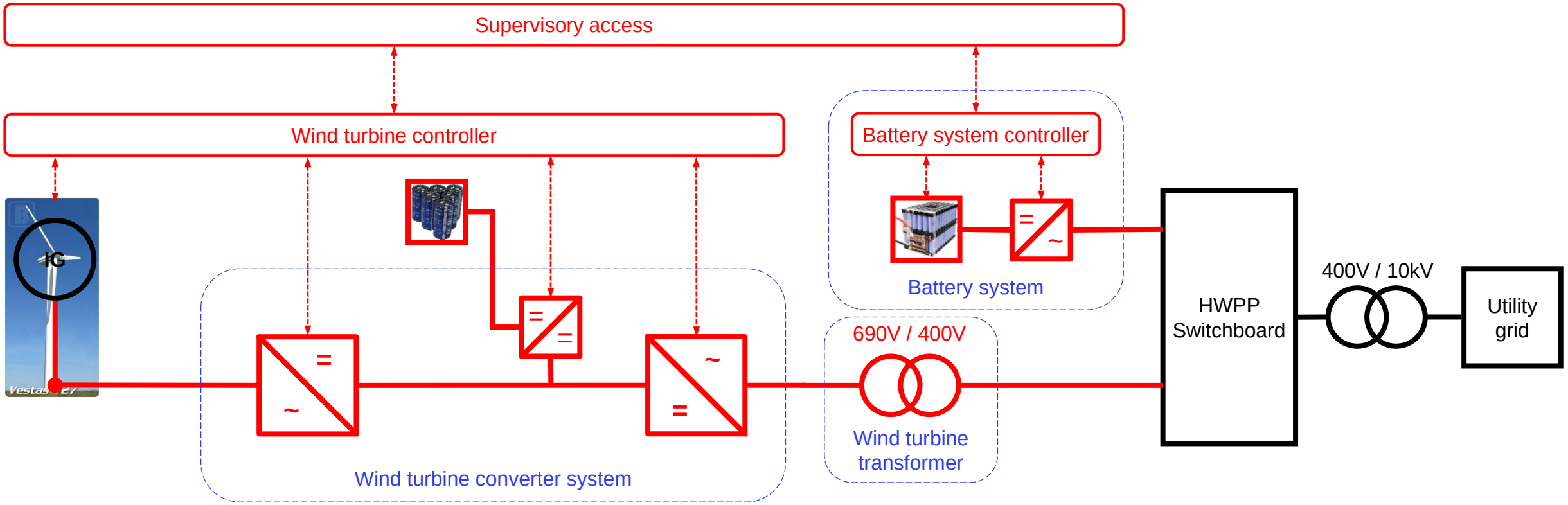
- Location:
  - DTU Wind Energy's wind turbine row in Risø Campus
- Phase 1:
  - Establish Hybrid Wind Power Plant (HWPP) switchboard
  - Time: Done 2020
- **Phase 2:**
  - **Retrofit to variable speed**
  - **Connect existing 225 kW V27 to HWPP switchboard**
  - **Add hybrid storage to V27 DC link**
  - **Time: 2021-22**
- Phase 3+:
  - Other power units (PV, additional storage, power2x)
  - Plant level control
  - Controllable grid interface
  - Time: 2022 and ahead



Phase 1: Switchboard front panel



Phase 2: – Retrofit and connection of V27



DTU

NEST

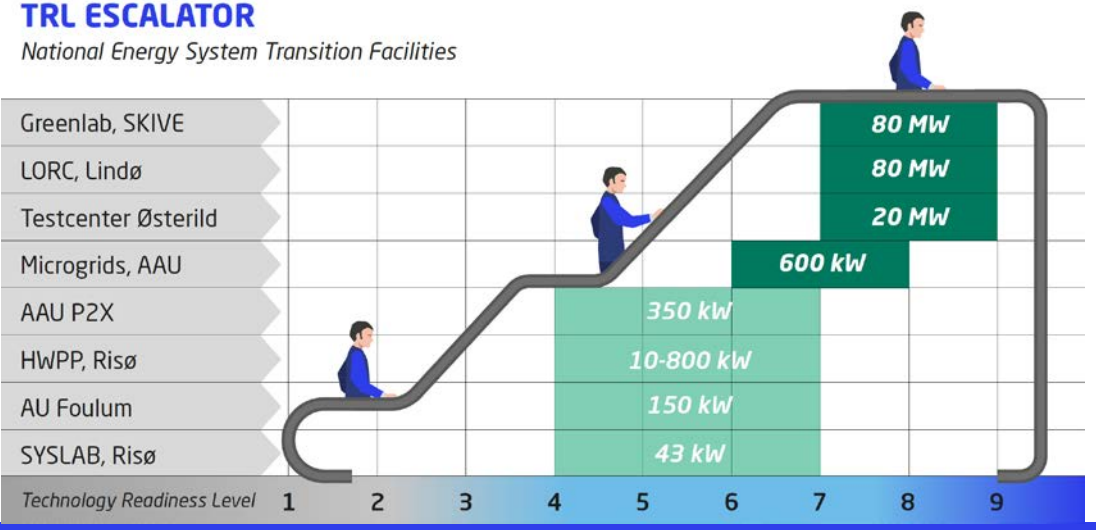
National Energy System Transition Facilities

On the national research infrastructure roadmap

Future prospects

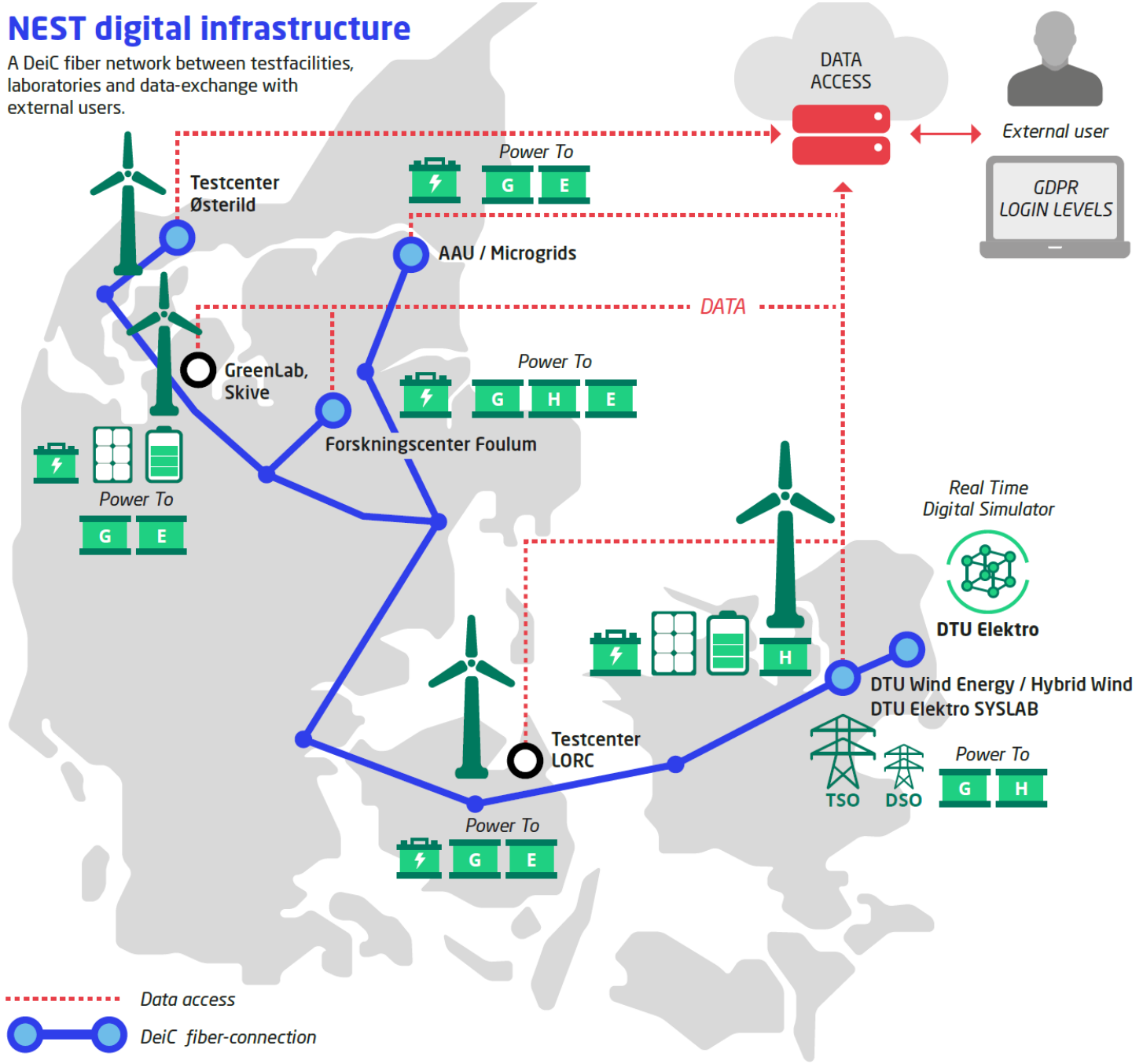
TRL ESCALATOR

National Energy System Transition Facilities



NEST digital infrastructure

A DeiC fiber network between testfacilities, laboratories and data-exchange with external users.



Danish Wind Hybrid Power Plant Forum

DTU Wind Energy
Department of Wind Energy

DTU Fotonik
Department of Photonics Engineering

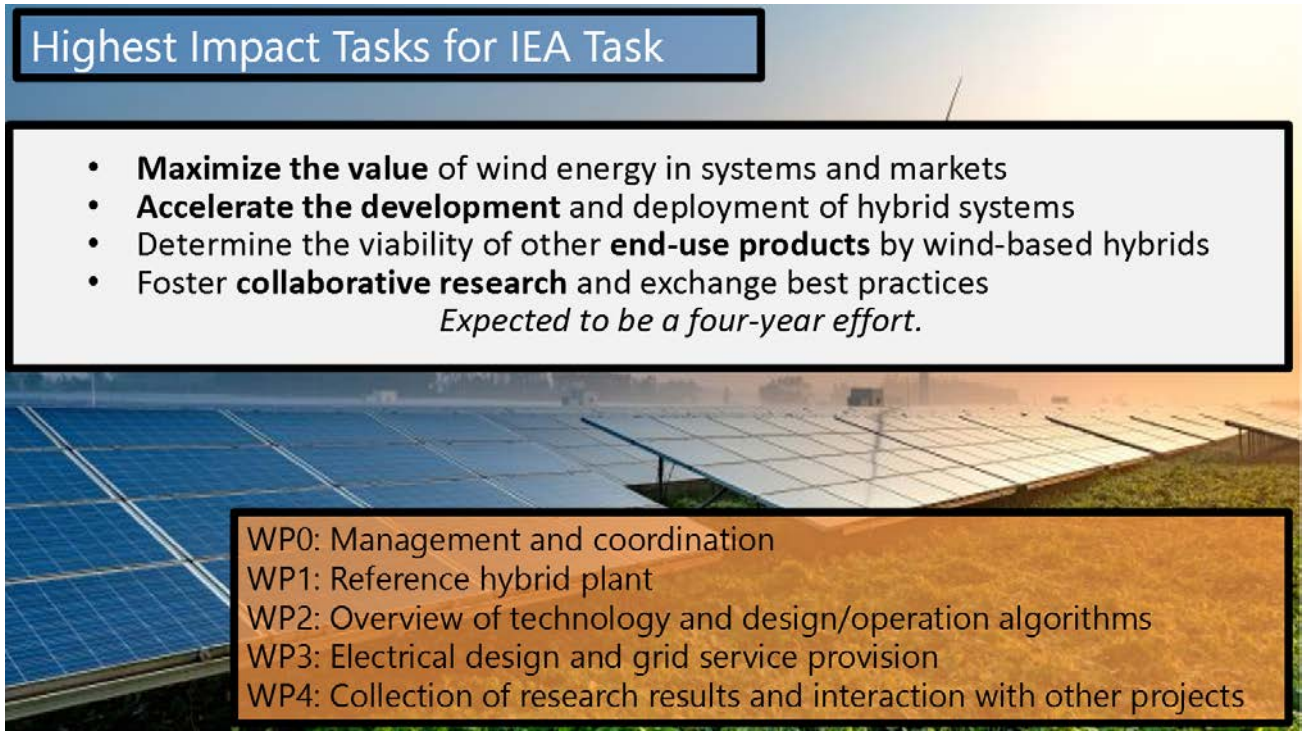
DTU Elektro
Institut for Elektroteknologi

DTU Energy
Department of Energy Conversion and Storage

IEA Wind Task 50: Hybrid Wind Power Plants

Operating agents:

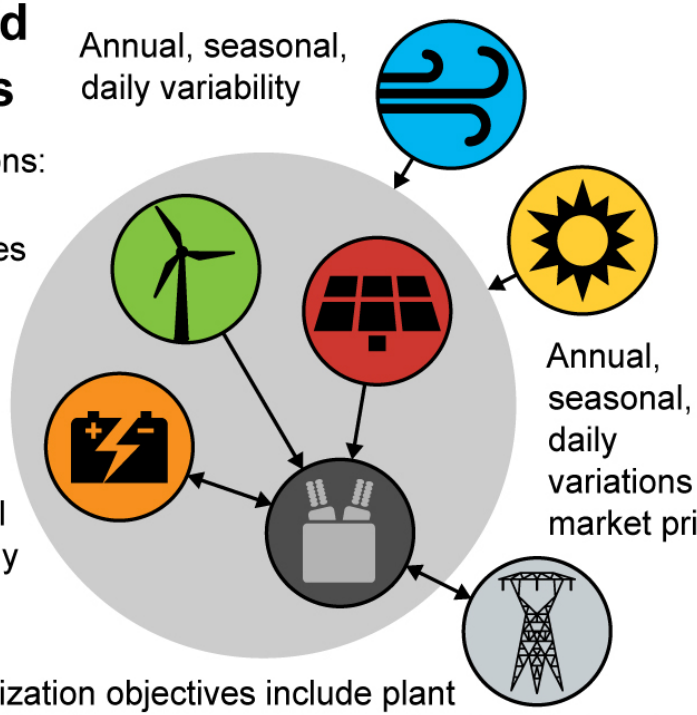
- Kaushik Das, DTU (DK)
- Jennifer King, NREL (US)



Future Hybrid Power Plants

Design Considerations:

- Number, type, and operation of turbines
- Number, type, and operation of solar panels
- Number and type of storage
- Overall layout of all assets and topology and sizing of collection system



Optimization objectives include plant profitability(net present value, payback period, etc)


DTU