Paris Session 2022

Blackstart Network Restoration using Wind Power with AC cables

SC C2 – 11152

NGN Showcase - August 2022

Leonel Noris Martínez

Researchers:

TenneT

Leonel Noris Martínez

Abdul Wahab Korai

DNV

Víctor García Suárez

Volodymyr Kalashnikov

Huub Pustjens

Matthias Müller- Mienack

Table of contents

01 **Objectives**

02 **WTG Modelling in PowerFactory**

03 **South Netherlands Test Grid**

04 **Simulation Results**

05 **Conclusions and Future Work**

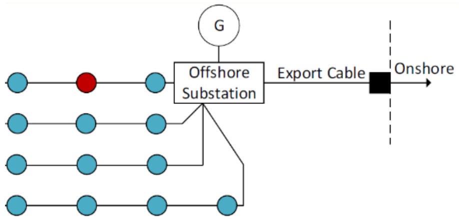
For power system expertise

01 Objectives

Objectives

Enabling the required Stages of Blackstart Restoration with Offshore Wind

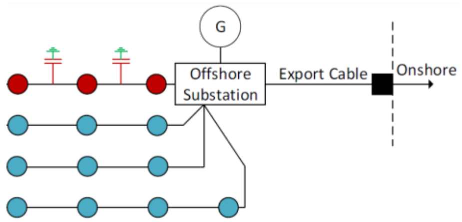
STAGE 1: Turbine self-start



Wind Turbine Generator (WTG) Manufacturer

- Self-start and power of auxiliary functions.
- Most turbines are already capable of delivering the service.

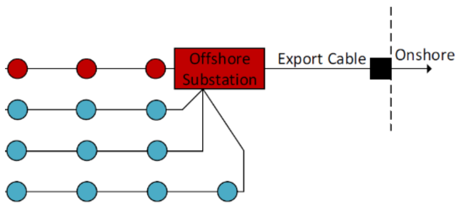
STAGE 2: Inter-array cables



Wind Farm (WF) Operator

- Turbines must absorb reactive power for the energisation of the inter-array cables.
- Turbines controllers must be suitable for weak grid conditions.

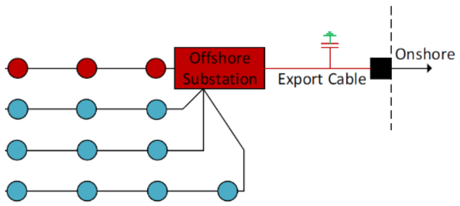
STAGE 3: Offshore substation



WF Operator

- Turbines must be capable of energising offshore substation's transformers.
- No need for diesel generator anymore.

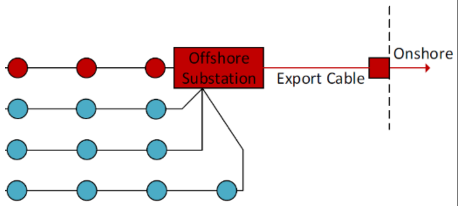
STAGE 4: Export cable



WF Operator

- Turbines must absorb more reactive power for the energisation of the export cables.
- Cable reactors will have an impact.

STAGE 5: Onshore grid



Grid Operator

- WF must comply with grid code requirements for i.e. voltage, frequency.
- Most technically demanding challenge.

Source: *Frazer-Nash, "Black Start Capability in the Wind Turbine Market", 2018.*

Objectives

Critical Technical Requirements and Challenges to be overcome

Inverter Control:
- The inverter control must be designed with grid-forming capability (focus on Type 4 WTG, i.e. full converter).
- The inverter control must be able to control voltage and frequency in a weak grid (i.e. similar to an AC voltage source).

Auxiliaries:
- The WTG must be able to supply a reduced and stable power output.
- Ideally, the WTG should be able to supply the WF auxiliaries. Normally batteries or diesel generators are used.

Wind Turbine Coordination:
- The WTG must be synchronised and paralleled to ensure stable operation, especially when the power output is low.
- The WF must be able to coordinate voltage control and load sharing among the available WTG.

Grid Energisation:
- Fast reactive power control by the WTG is critical to energise transformers and lines/cables.
- Constantly match generation supply and load demand at all times including contingencies.
- The reactive power capability of the WTG will determine the units required for each energisation process.

Wind Availability:
- Sufficient wind resources must be available during the entire restoration process.
- Reliable wind forecast can help mitigate the risk of wind intermittency.
- Offshore wind seems promising as a Blackstart Restoration method for transmissions grids.

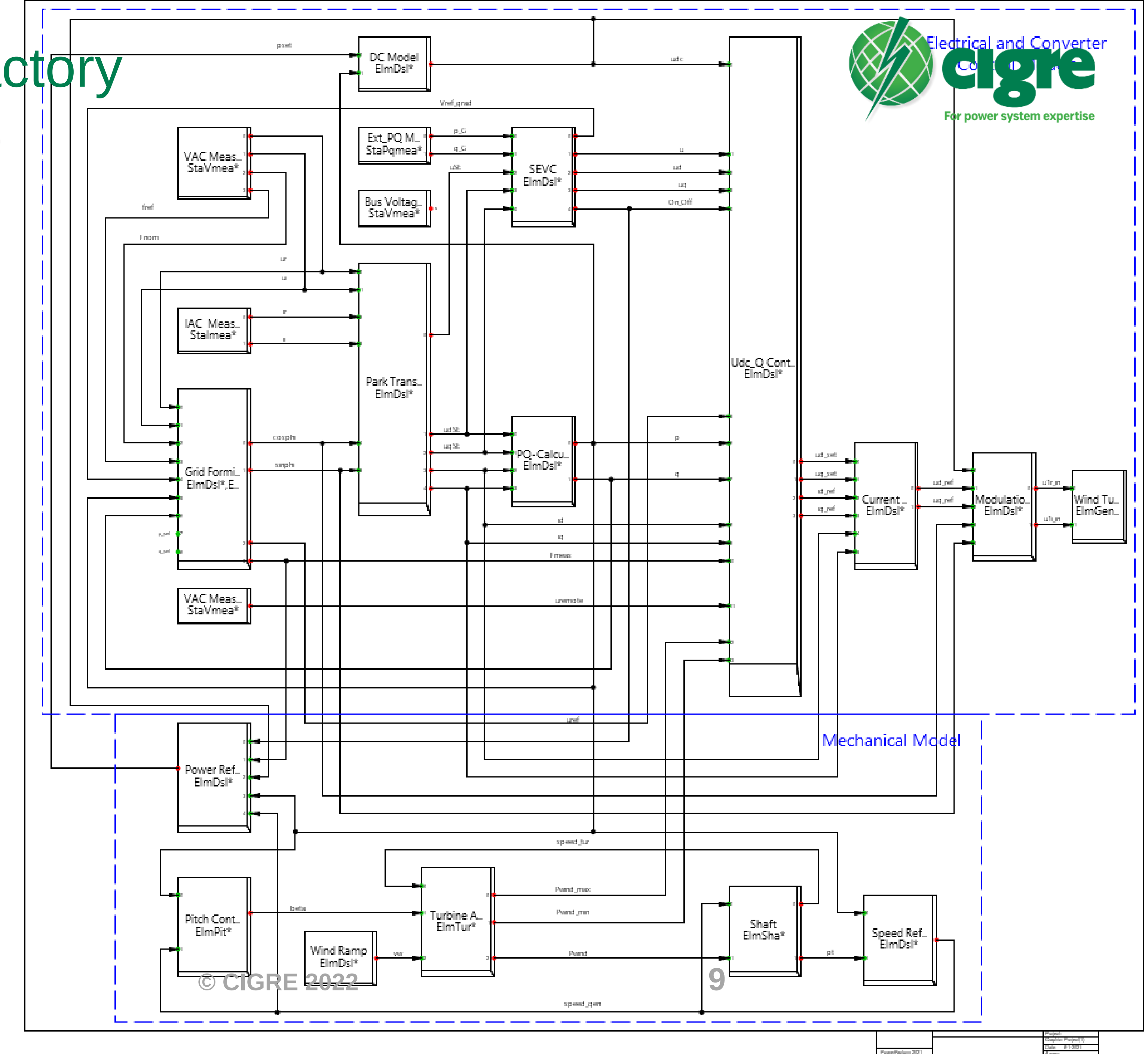
02 WTG Modelling in PowerFactory

WTG Modelling in PowerFactory

Type-4 WTG Frame

- Simplified WTG model scaled 50 times (WF).
- Aerodynamics considered.
- Mechanical model considered.
- Linear function for represent wind availability/gusts.
- Includes reactive power (*q)* / voltage (*v*) control and voltage-dependent frequency (*f)* control.
- Includes under/over-frequency fast active power (*p)*/*f* control (outside ±0.2 Hz).
- Power balance between WTG and converter side considered.
- Switch between grid-forming mode with droop control or grid-following mode with PLL.
- DC circuit dynamics are explicitly represented.
- Input power for DC circuit is constant.
- Chopper protection is included.
- Ramping Soft Energisation voltage control [p.u./s] with PI controllers.

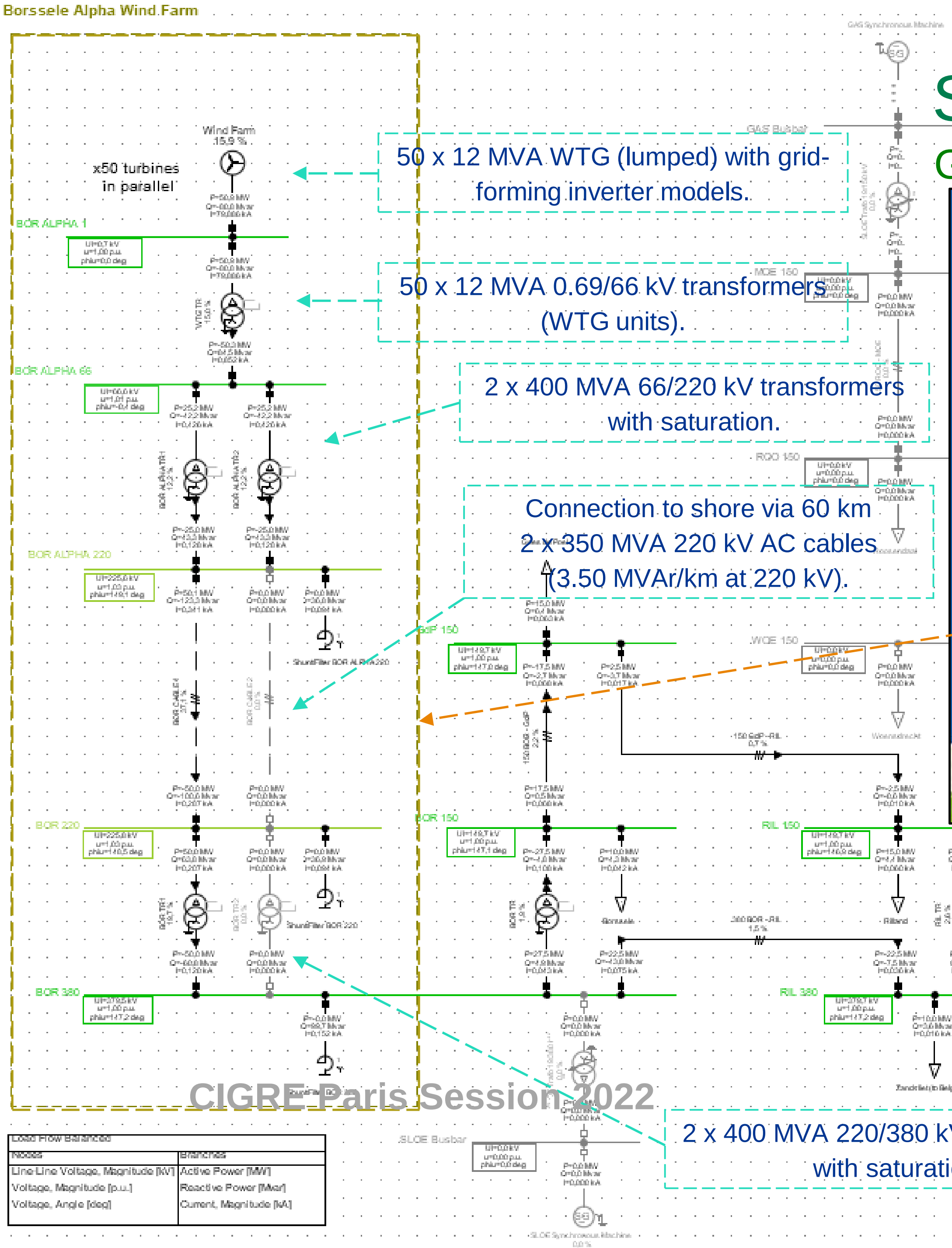
Type 4 Wind Turbine Generator Dynamic Frame

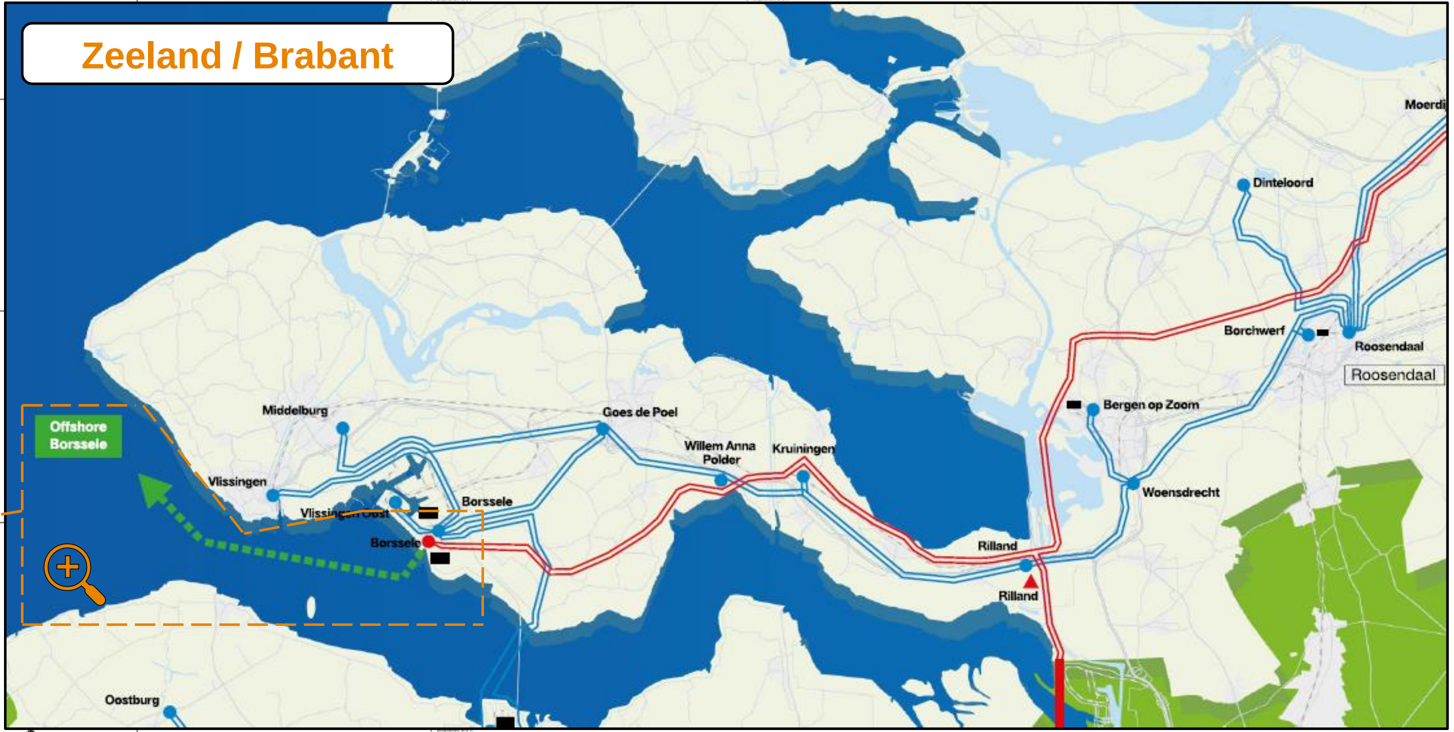


03 South Netherlands Test Grid

South Netherlands Test Grid

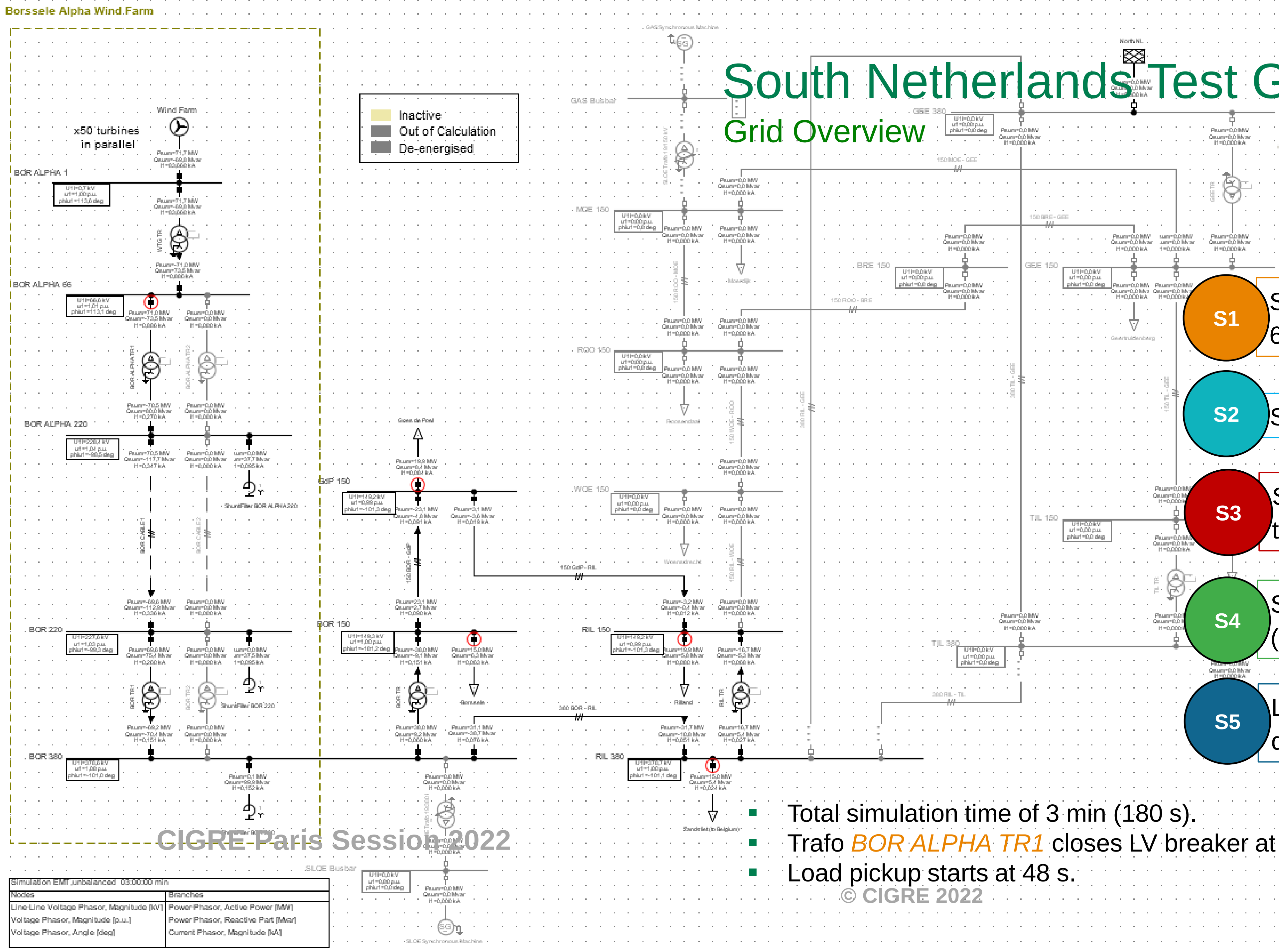
Grid Overview





South Netherlands Test Grid

Grid Overview



S1 Soft-energisation (SE) of a 400 MVA 66/220 kV transformer.

S2 SE: 350 MVA 220 kV cable to shore.

S3 SE of a 400 MVA 220/380 kV and two 500 MVA 380/150 transformers.

S4 SE of 380 kV (42 km) and 150 kV (12 and 30 km) overhead lines.

S5 Load pickup of 4 loads with demands between 20 to 32 MW.

- Total simulation time of 3 min (180 s).
- Trafo *BOR ALPHA TR1* closes LV breaker at 0,015 s.
- Load pickup starts at 48 s.

04 Simulation Results

Simulation Results

Blackstart of WF composed of 50 WTG 12 MVA 0.69 kV

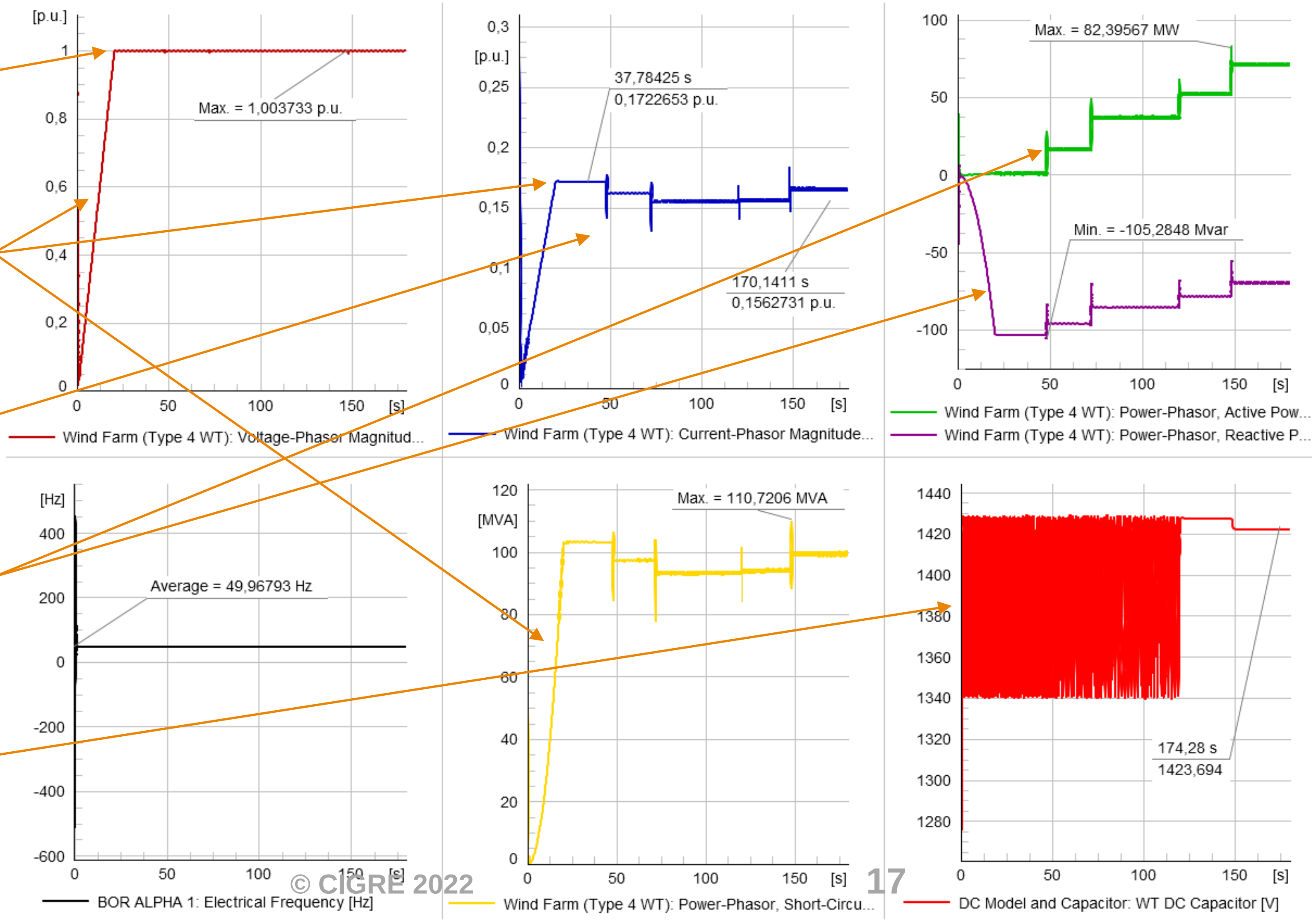
WF terminal voltage successfully ramped up to 1 p.u. Is important to keep that value, as otherwise unwanted tripping and maloperation may surge.

The Soft Energisation Method caters a controlled ramp up of 0,05 p.u. voltage/current/power per second.

As load pickup starts and progress, the maximum current in the WF decreases proportionally with load pickup.

As load pickup starts and progress, reactive power absorption decreases and active power supply increases.

The converter DC chopper activates and keeps the DC voltage to its limits until this voltage is employed in the load pickup stage.



Simulation Results

Aero-Mechanical behaviour of the aggregated 50 WTGs

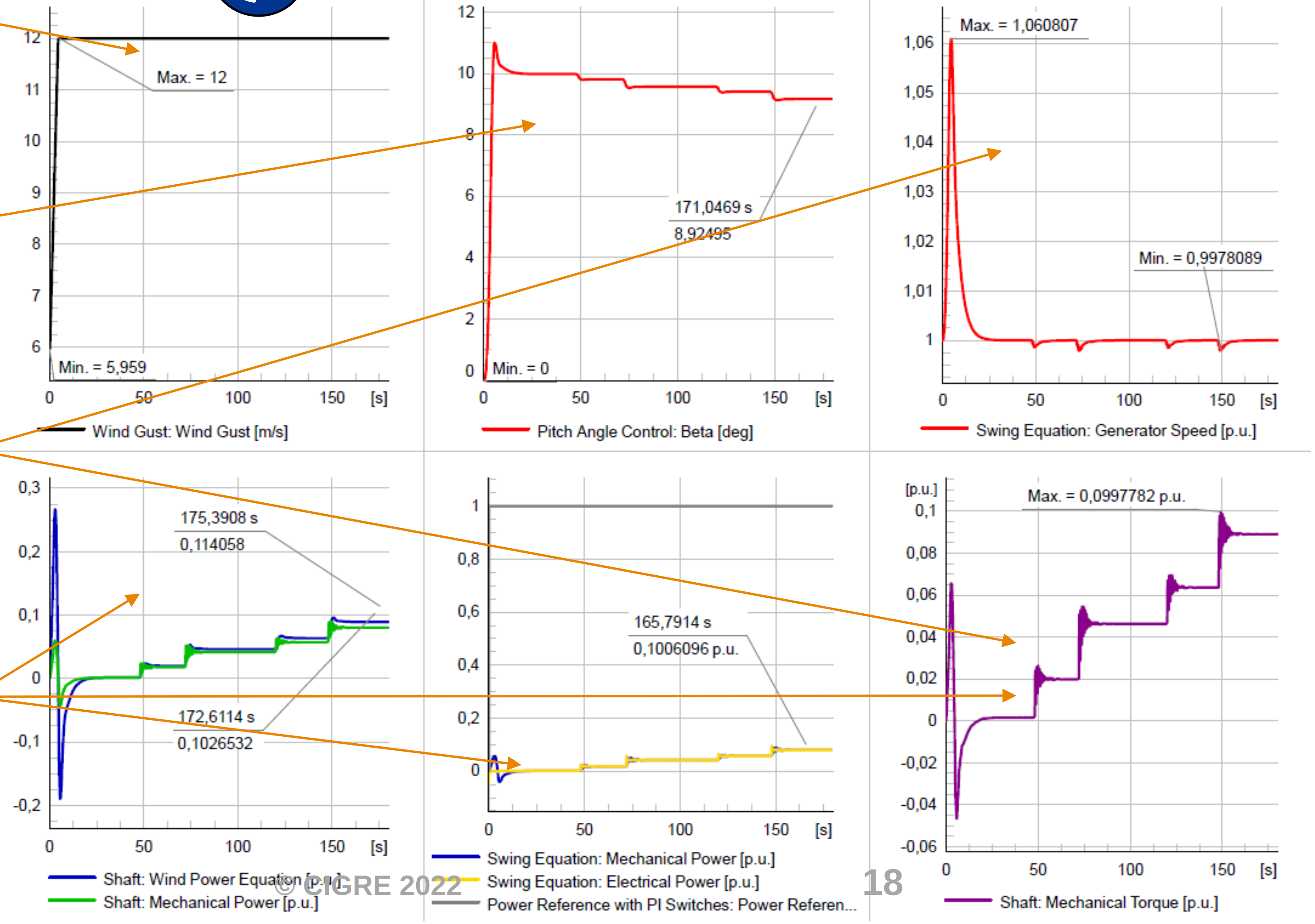
There is an obvious trend seen in all the aero-mechanical plots which in turn also match with the electrical behaviour results of the WF, as all of the plots present the same events occurring at the same time.

Linear equation that represents a simple wind gust that can be set up and modified in the PowerFactory Common Model while simulation is running.

The pitch angle control decreases its degrees as soon as it senses more power collected from the wind is necessary to deliver as more loads are brought up online.

The swing equation model remains constant in terms of speed, however, the torque changes against time due to the growing demand of passive network elements and loads being restored.

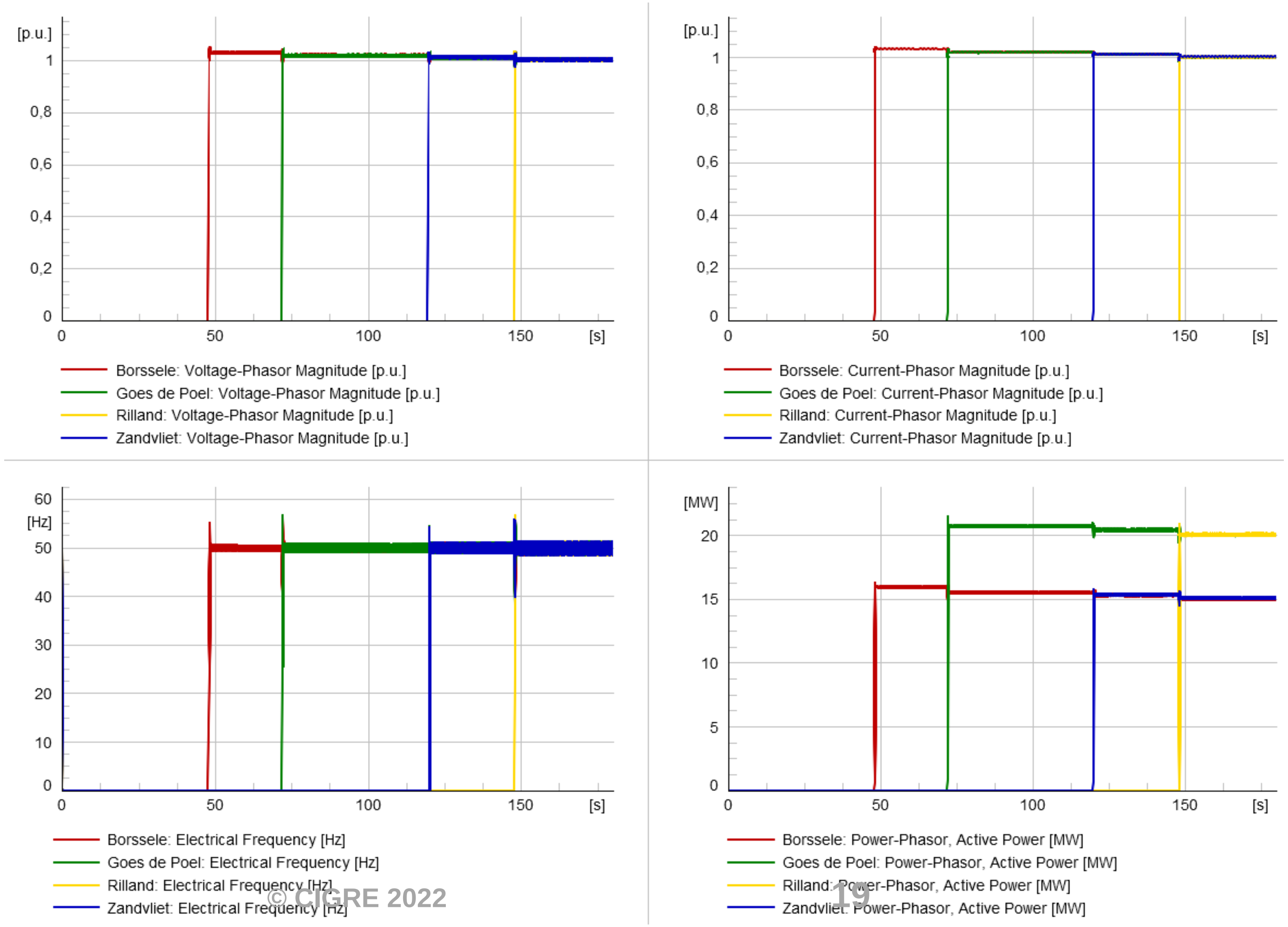
The wind power equation, the mechanical power of the WF and the electrical power of the WF they all have very similar behaviours although there can also be seen some losses between the several energy transfer phases.



Simulation Results

Load pickup of several loads between Zeeland/Brabant

The load pickup stage starts at 48 s; four loads were successfully restored with three minutes of blackout, each with their nominal voltages, load demand and frequency restored.



05 Conclusions and Future Work

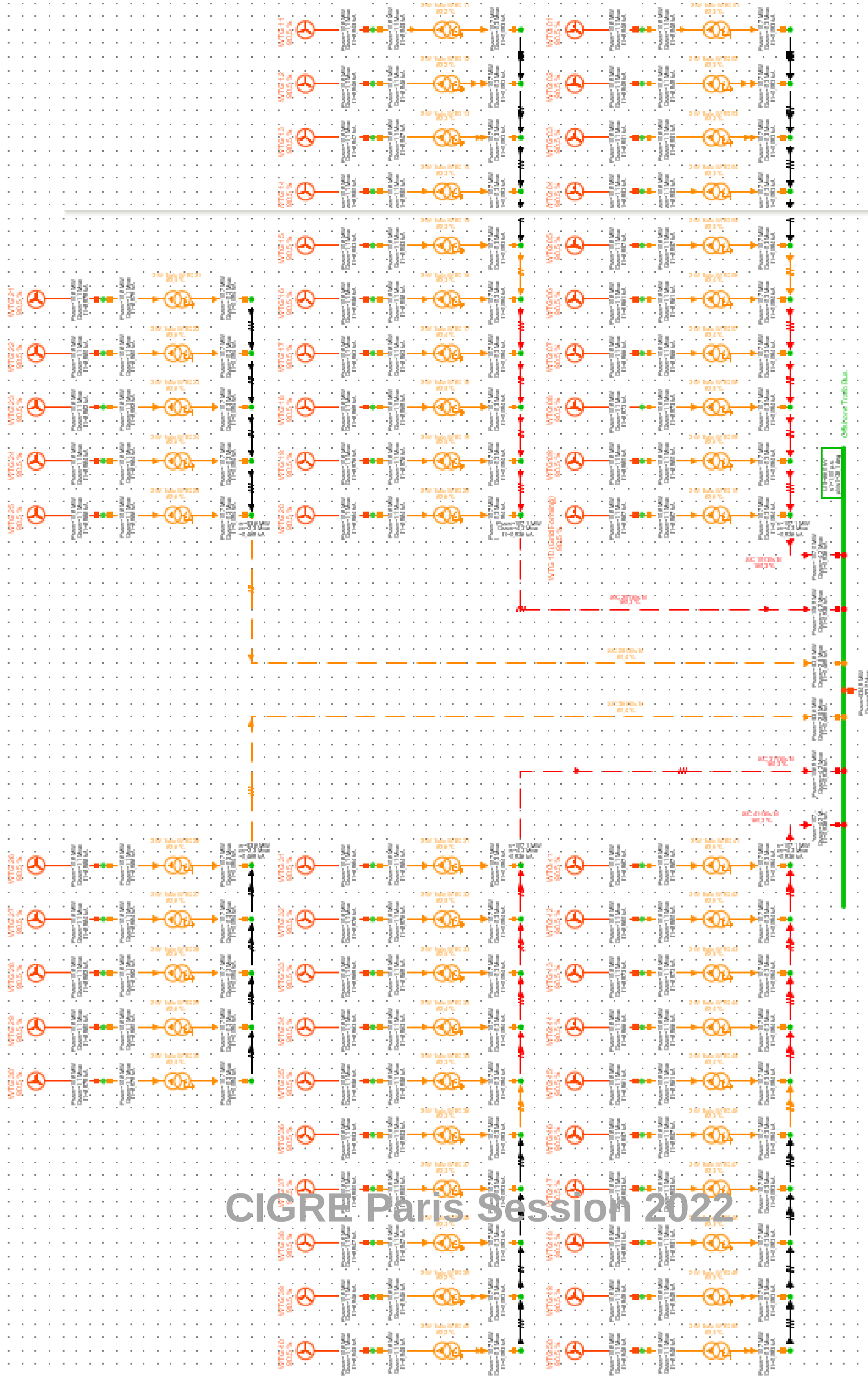
Conclusions

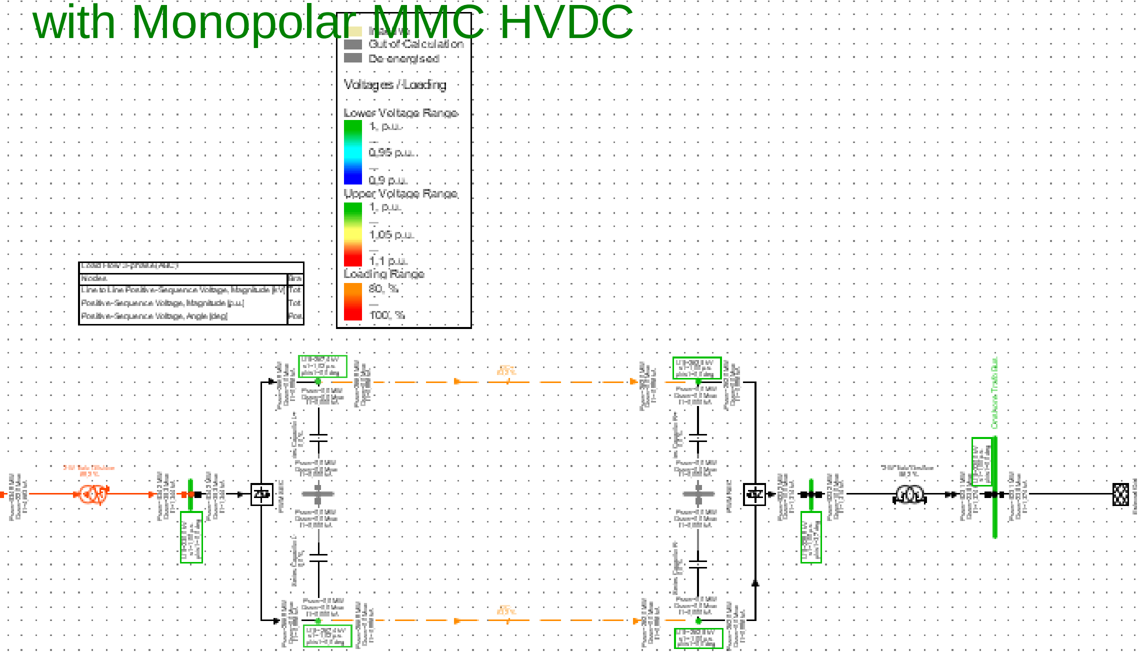
Network Restoration using Wind Power with AC cables

- Key issues: Auxiliary load, WTG coordination, wind availability (preference for offshore wind) and reactive power.
- Soft Energisation of transformers/cables is advised since the WTGs do not provide short-circuit power (inverters cannot handle the inrush currents and voltage distortions produced during (standard) Hard-Energisation).
- For Offshore WF (OWF), the reactive power generated by AC cables must be absorbed by the inverters. For long cables this means that a significant number of the total WTGs must be operating (also reactors required).
- Resonance/saturation oscillations greatly reduced compared to (normal) Hard Energisation.
- **Successful Blackstart Restoration.**
- Parameters according to desired demand of loads.
- Frequency stable at approx. 50 Hz. However, saturation effect caused by the EM properties of transformers, cables and incorporation of loads.
- **Energisation of the AC onshore network by VSC-MMC-HVDC system connected OWF replacing the AC cables should be investigated in detail using the control approach presented in this presentation.**

Future Work

Network Restoration using Offshore Wind Farm with Monopolar MMC HVDC

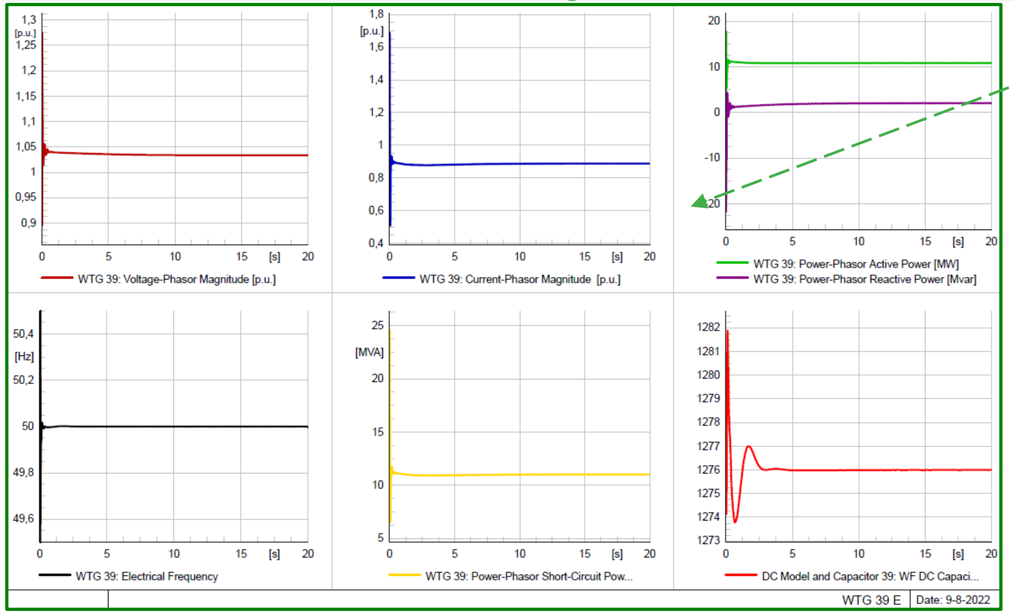




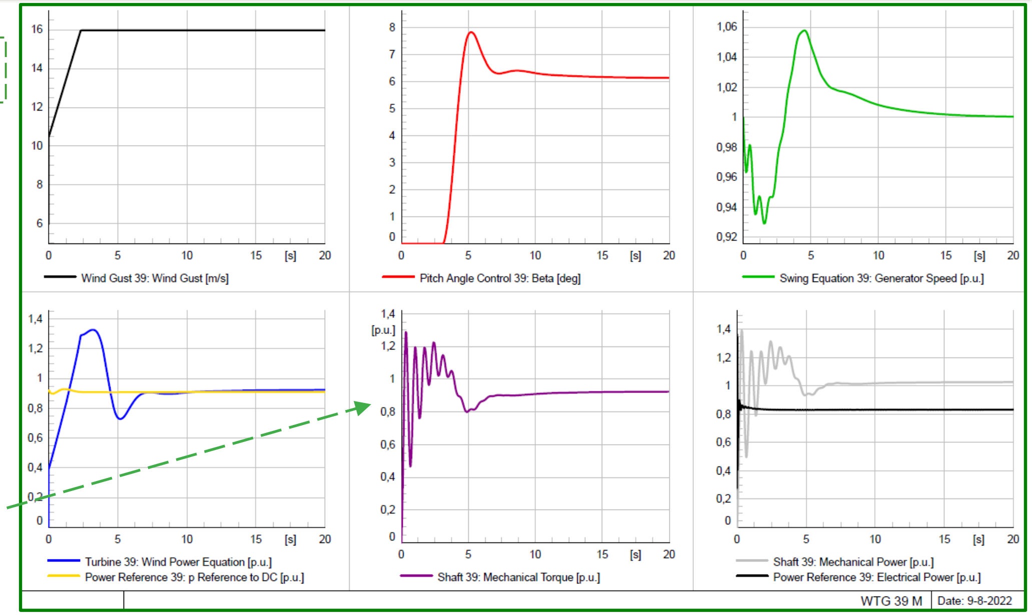
- Same WTG model physically copied 50 times (OWF).
- OWF paired with a Monopolar MMC HVDC system and 100 km DC lines.
- Key issues: Auxiliary load, WTG/HVDC coordination, wind availability and reactive power control.
- Model EMT simulation for 20 [s] with no events (for normal operation validation).
- No faults neither Blackstart events yet.

Future Work

Network Restoration using Offshore Wind Farm with Monopolar MMC HVDC

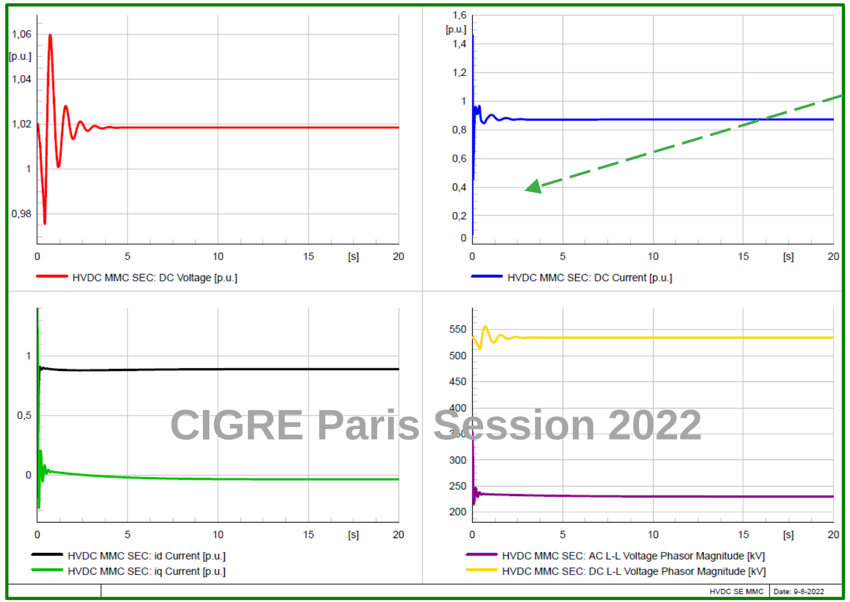


WTG 39 Electrical Plots.



WTG 39 Mechanical Plots.

HVDC Sending-End MMC Plots.



Onshore Busbar Plots.