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Study Committee C2

Operation and Control

Paper ID 11152_2022

Blackstart Network Restoration using Wind Power with AC cables

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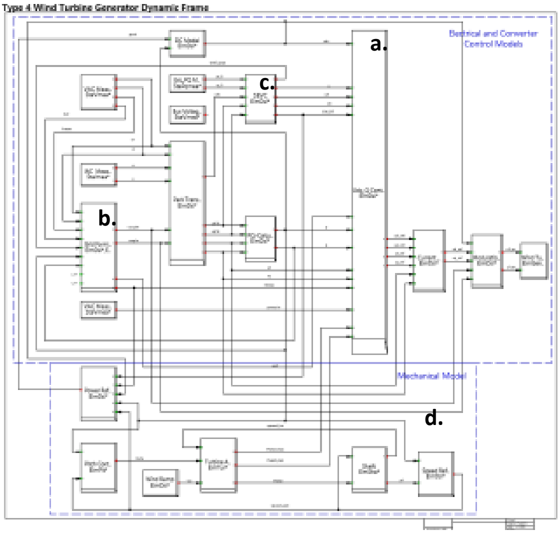
Motivation

1. World agenda imposing the renewable energy transition.
2. Renewable energy systems (RES) have not yet mature technology regarding grid-forming converters, neither are full-capable yet for leading a Blackstart Restoration process after a blackout fault.
3. Not enough simulation models available for evaluating the potential of offshore wind farms (OWF) as grid-forming blackstart-capable generators.

Method/Approach

1. Modelling of wind turbine generators (WTG) and their controls in DIgSILENT PowerFactory.
2. Use of a generic WTG model as a base frame, which was upgraded with:
   a. WTG Reactive Power/DC Voltage Converter Control Loop.
   b. Grid-Forming Droop Control/PLL Loop.
   c. Soft Energisation Voltage Control Loop.
   d. Aerodynamic and Mechanical submodels (detailed blocks not visible in poster).

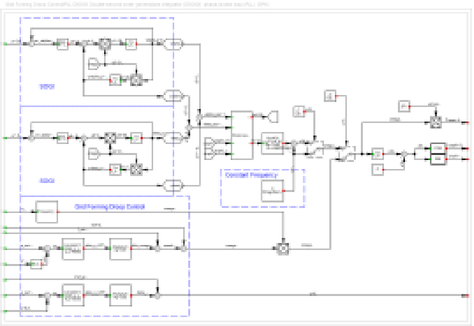
Type 4 Wind Turbine Generator Dynamic Frame



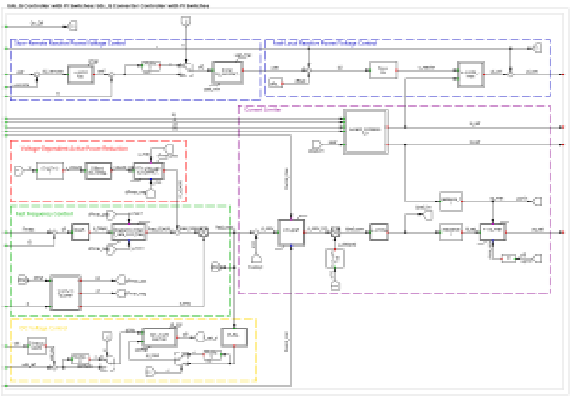
Investigation Objective

1. With the WTG model with the Soft Energisation, Reactive Power/DC Voltage Converter, and the Grid-Forming Droop Control Loops, the objective of investigation is to assess the WTG model under an blackout scenario to evaluate if such design is capable to restore and form the outaged grid.
2. Evaluation of the performance of the aero-mechanical submodels responses in relation of their electrical parameters counterparts.

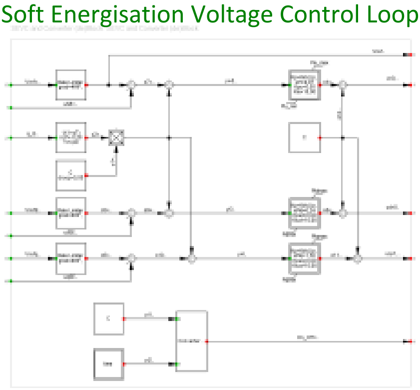
b. Grid-Forming Droop Control/PLL Loop



a. WTG Reactive Power/DC Voltage Converter Control Loop



c. Soft Energisation Voltage Control Loop



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Blackstart Network Restoration using Wind Power with AC cables (2)

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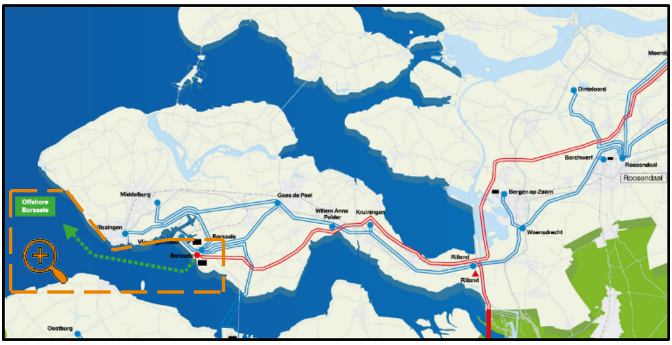
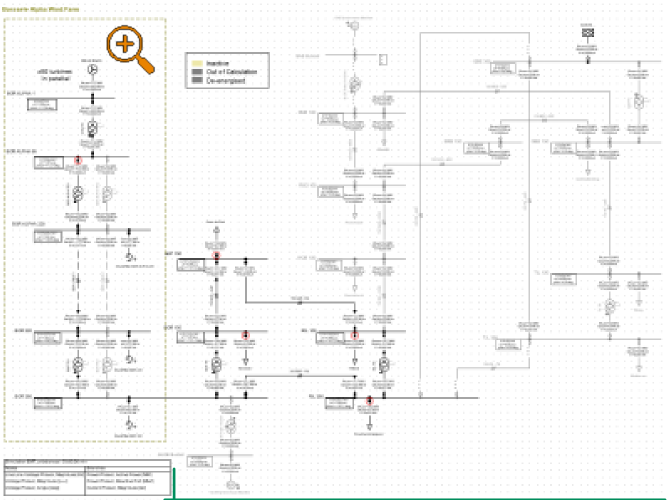
Experimental Setup

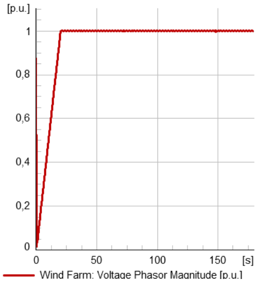
1. The Study Case is a simplified grid representing the Zuid-West Transmission Grid of the Netherlands.
2. 3-minute EMT simulation setup presenting the WTG aggregated 50 times to resemble an OWF with the following events:
   a. LV breaker of offshore 400 MVA 66/220 kV BOR ALPHA TR1 transformer closes at 0,015 s.
   b. Commence of Soft Energisation process of BOR ALPHA TR1 transformer.
   c. Soft Energisation of 350 MVA 220 kV 60 km cable to shore, one 400 MVA 220/380 kV and two 500 MVA 380/150 transformers, and of several OHL (380 kV-42 km and 150 kV-12 and 30 km.
   d. Load pickup of 4 loads with demands between 20 to 32 MW after 48 s.

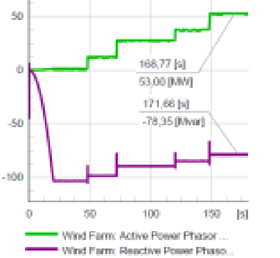


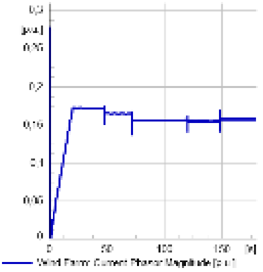


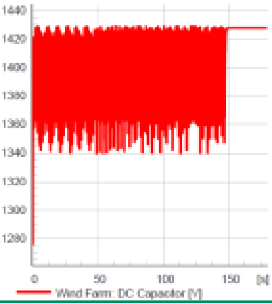
Test Results

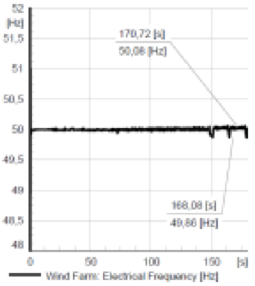
OWF Electrical Plots



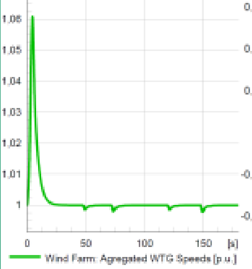


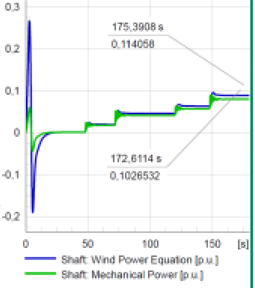


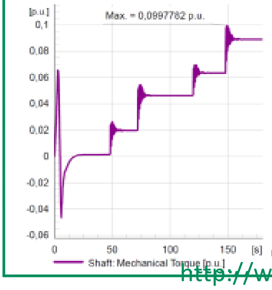


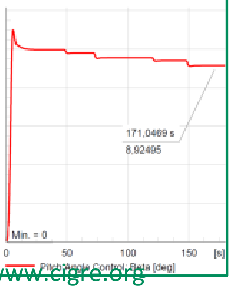


OWF Mechanical Plots









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Blackstart Network Restoration using Wind Power with AC cables (3)

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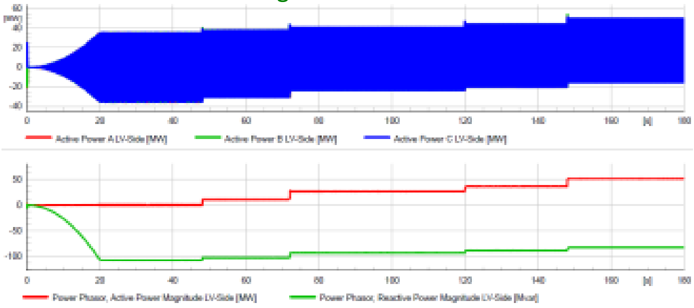
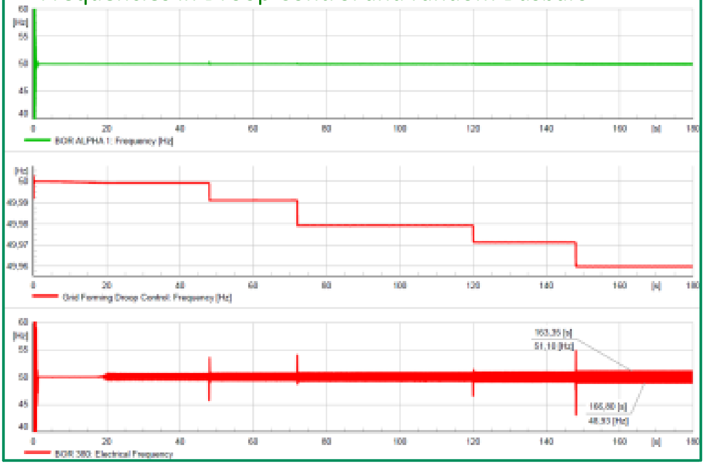
Test Results (2)

Transformer Soft Energisation Plots



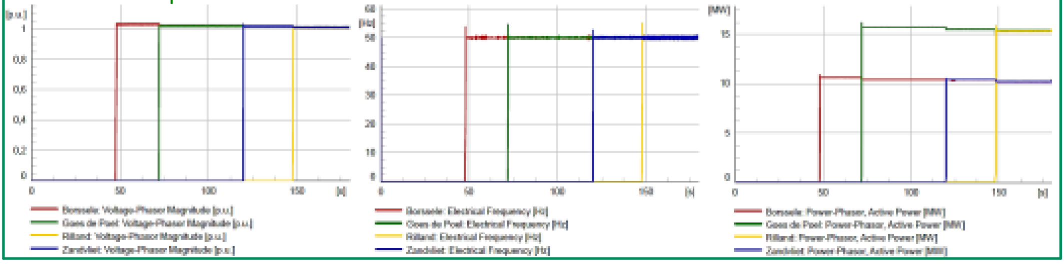
Frequencies in Droop Control and random Busbars



Discussion of Results

1. WF terminal voltage successfully ramped up to 1 p.u. The Soft Energisation Method caters a controlled ramp up of 0,05 p.u. voltage/current/power per second.
2. As load pickup starts and progress, the maximum current in the WF decreases proportionally with load pickup, reactive power absorption decreases and active power supply increases.
3. 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.
4. 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.
5. 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.
6. Frequency stable at approx. 50 Hz. However, saturation effect caused by the EM properties of transformers, cables and incorporation of loads.
7. Four loads were successfully restored with three minutes of blackout, each with their nominal voltages, load demand and frequency restored.

Loads Pickup



Conclusions

1. Key issues: Auxiliary load, WTG coordination, wind availability (preference for offshore wind) and reactive power.
2. Soft Energisation of transformers/cables is advised since the WTGs do not provide short-circuit power.
3. 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).
4. Resonance/saturation oscillations greatly reduced compared to (normal) Hard Energisation.
5. Successful Blackstart Restoration. Parameters according to desired demand of loads.

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