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Laboratory test setup for offshore wind integration with the stand-alone electric grid at Oil and Gas offshore installations

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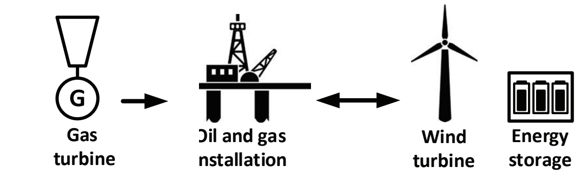


Objective

The objective of the presented work was to establish a laboratory Power Hardware-In-the-Loop setup to allow testing and demonstration of the operation of offshore wind integrated with the stand-alone electric grid at oil and gas offshore installations.

Intended use

The intended use of the laboratory setup is to validate simulation results in an environment one step closer to the real world, typically evaluation of different power management, wind turbine and battery system converter control strategies. This may include validation of fast acting power management strategies that utilizes storage for dynamic support, decentralized (autonomous) control, wind turbine converter control, virtual synchronous machine control principles, converter reactive power control, turbine pitch control, wind turbine inertia, load control and load shedding. The setup can also be used for validation of control strategies for handling of contingencies such as tripping of wind and gas turbines, start of large motors and large load steps.

Power Hardware-In-the-Loop (PHIL)

The concept of PHIL is to use a real time simulator in combination with a power amplifier to replicate part of a power system in a laboratory setup. PHIL is an established methodology for laboratory tests that drastically reduces the cost involved and gives a lot more flexibility in what can be tested. It can also reduce the risk and safety issues related to the laboratory testing.

The PHIL concept is illustrated in Figure 2. Figure 3 shows the actual laboratory implementation, that is, the components and systems included as real (down-scaled) hardware and the simulated components and systems emulated by the real-time simulator/ power amplifier.

In this setup, the real hardware part is scaled down to 380V level. The power amplifier (Figure 1) is a 200kVA, 5kHz bandwidth amplifier installed in the National Smartgrid Laboratory at NTNU/SINTEF. The setup can easily be adapted or extended according to the needs. It is in particular easy to change the simulated part. More elements can also be added as real components.

Figure 1 The Egston Power amplifier used in the PHIL setup

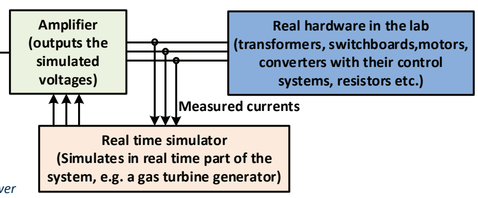
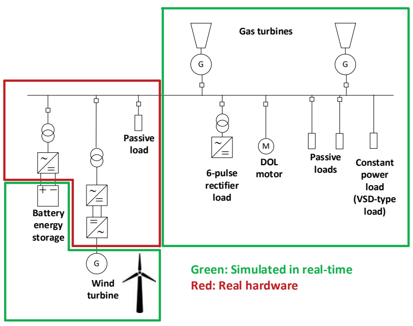


Figure 2 The PHIL concept



Case data:

11 kV Main bus voltage
13 MW Gas turbine generator:
- speed droop control mode
- droop based automatic voltage controller

10 MW wind turbine with full power converter:
- reactive current controlled to zero (no AC voltage support in this case)
- DC-link voltage control by grid side converter
- No utilization of wind turbine inertia

5 MW energy storage:
- Configured for frequency support based on frequency measured by local phase locked loop
- Control independent of power measurements from generators and load.
- Control principle compatible with both isochronous speed and droop-controlled generators
- Reactive power controlled to zero (no AC voltage support in this case)

Loads:
- Mix of passive and constant power type loads (VSD-type loads) and a 650kW direct online induction motor

Figure 3 The current PHIL laboratory configuration for offshore wind integration with the stand-alone electric grid at Oil and Gas offshore installations

PHIL validation example

Two tests are shown, starting from same initial condition. Breaker (1) and (2) in Figure 3 were closed at time zero in one test each. The resistance and inductance of the simulated resistor ((2) in figure 3) and the real world resistor ((1) in figure 3) are chosen such that they are equivalent for the voltage and power levels used in the simulated and real world systems.
The test shows that the load step increase in the simulated part of the test setup is equivalent to the load step increase in the real hardware part of the laboratory setup. Sample results are shown in Figure 4.

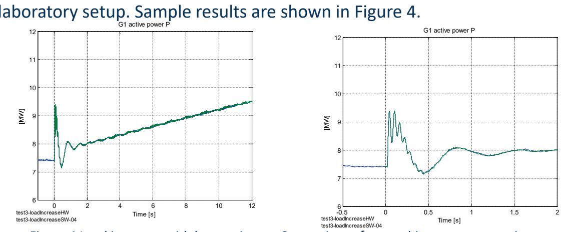


Figure 4 Load increase, with battery in use. Comparison of gas turbine generator active power transients after connecting load in simulated (green) and real HW (blue). Right plot is a zoomed version of the left. The results confirms that the PHIL concept works as intended.

Sample result: Wind power fluctuations

The effect of fluctuations in wind power production on Oil and Gas installation AC bus frequency is shown in Figure 5, both with and without inclusion of a battery energy storage, The battery storage controller senses variation in bus frequency and counteracts the wind power fluctuations such that bus frequency fluctuations are significant reduced. Playback of a real, measured, wind power series from a wind turbine in operation were used in this test.

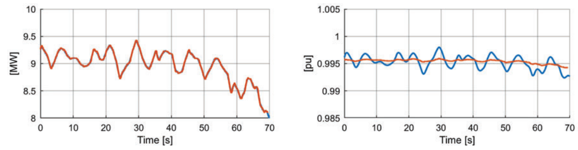


Figure 5 Laboratory results showing (a) wind power production [MW] and (b) bus frequency [p.u.] of the Oil and Gas installation power system for operation with (red) and without (blue) an energy storage for transient support (results scaled to real system power level).

Sample result: Trip of wind turbine

The effect of tripping one wind turbine operating at ~9MW production is shown in Figure 6, both with and without inclusion of a battery energy storage. The battery storage controller senses reduction in bus frequency and reduces the frequency drop by delivering active power to the grid.

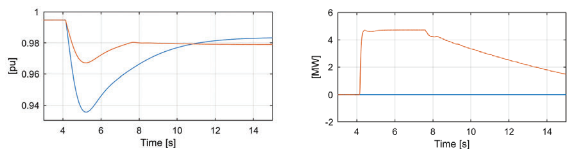


Figure 6 Laboratory results showing (a) bus frequency [p.u.] and (b) battery converter power flow [MW] for operation with (red) and without (blue) an energy storage for transient support after trip of wind turbine.

Conclusions

The laboratory setup has been effective in validating the simulation results in an environment one step closer to the real world. The experiments show that paralleling of both wind and gas turbines actually reduces both voltage and frequency variations compared to operating the same gas turbines as the only source of energy. They also confirm that the energy storage systems are able to significantly stabilize and reduce the transients of both frequency and voltage. The results are not generally valid for all oil and gas installations. The proposed laboratory approach is a cost-effective improvement in identifying potential operational bottlenecks in the new control strategies that combines gas turbines in the stand-alone electric grid at oil and gas installations with new wind turbines and energy storage solutions.

The project

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