

# New-generation DFIG power converters for 6-8 MW wind turbines

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DFIG topology wind turbines have been widely used in the wind energy market during the last years to cover the medium and lower power ranges, between 2 and 4 MW. Nowadays, this fact has changed and the OEMs are developing DFIG wind turbines that could go above power rates of 6 MW.

The wind sector is globally focusing its efforts on reducing the Levelized Cost of Energy (LCoE) of the technology in order to prove itself as a profitable option in the energy mix regarding electrical generation. In response to this market outlook, OEMs are working hard to develop wind turbines with a power range exceeding 6 MW, which potentially enables the reduction of the LCoE of the wind farm.

In addition, the increasing penetration of

wind power capacity into the grid creates new challenges for the Transmission System Operators (TSO) in order to keep the stability of the transmission system. As a consequence, grid codes around the world are strengthening their requirements to meet more demanding conditions such as FRT (Fault Ride-Through) behavior or harmonic distortion compliance.

The main constraints of the DFIG topology, such as short-circuit peak currents or grid

code compliance, have in the past limited a power increase. In depth knowledge of wind industry features, DFIG generators and core components of a power converter are the key factors to ensure a robust and reliable solution regarding the different events that could occur, such as harmonic fulfilment, FRT, weak grids, SSR, etc.

Ingeteam's new generation of power converters apply the most advanced control strategies, state of the art

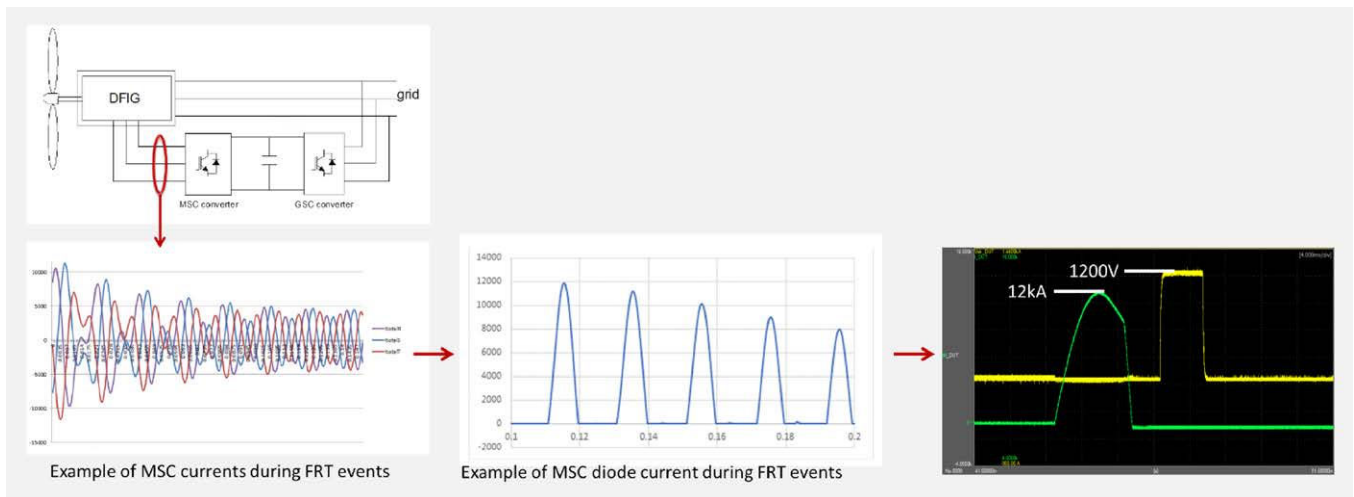


Figure 1. FRT peak currents injected to a FF1400R17IP4 Infineon module.

semiconductor technologies and cooling strategies that solve the main constraints of the DFIG topology, allowing for an increase in the power rate of the new wind turbines above 6 MW.

#### State-of-the-art technology for high power converters

The upgrade of the power converter to power rates above 6 MW requires a detailed knowledge of DFIG features, especially the main design constraints of this topology, like the peak currents during FRT events, or the mechanical behavior of the whole converter inside the wind turbine. The design process followed by Ingeteam covers all these aspects and the new generation products ensure the reliable operation of the system.

Apropos FRT events from the HW perspective, the semiconductor is one of the most critical points with regards to product lifetime. High peak currents, generally ranging from 8kA to 14kA, can limit the design, and thus, a thorough knowledge of each module under this operation mode is required. Ingeteam, taking advantage of its high-tech

laboratory and specific test benches, has the capability of testing the semiconductors under all operation ranges, including different FRT profiles with real voltage and current conditions.

The figure above shows a peak of up to 12kA introduced in one FF1400R17IP4 IGBT, followed by the blocking voltage of the real application: Figure 1.

This kind of semiconductor characterization is essential to know the real application limits of each semiconductor module. This knowledge is also relevant to adapt and optimize the power converter design depending on the FRT specification and generator characteristics. In this way, the modular solution offered by Ingeteam for the new generation of power converters complies with two main goals, reliability and cost optimization for each application. This is key to keeping the competitiveness in wind markets.

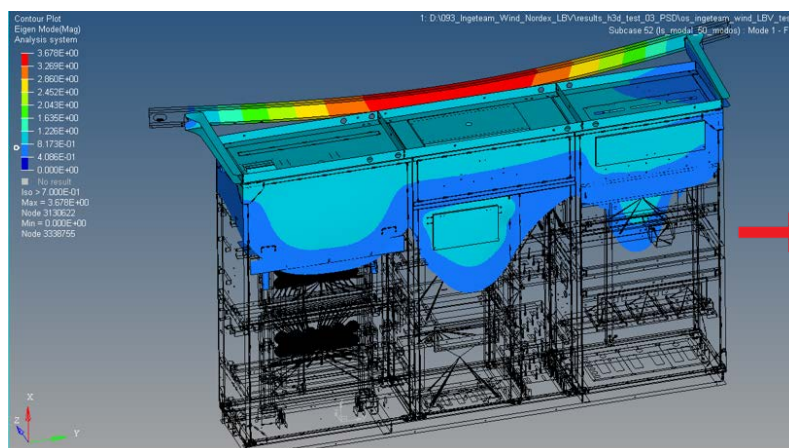
The mechanical performance is also fundamental in arriving at a successful design. Ingeteam has vast experience in the wind industry with a wide variety of

designs and locations inside the wind turbine. Finite element analysis (FEM) of the whole converter cabinet is always performed before real certification tests. The two-step validation process guarantees a lower time to market of compliant solutions: Figure 2.

Another important design criterion is the cooling of the whole converter cabinet. At the end, improving the cooling has a direct impact on the final power rate of the converter. Computational Fluid Dynamics simulations (CFD) are necessary to reach the best cooling performance. Ingeteam performs these analyses starting directly from the junction of the semiconductor and reaching the whole converter cabinet, including the air and liquid cooling of passive elements such as filters.

Depending on the wind turbine design different cooling strategies apply. Full liquid-cooled options allow an extraction of all the losses through the liquid, avoiding heat exchange with the internal ambient of the wind turbine. This option becomes more interesting for high power wind turbines, where the heat generated by all

#### FEM SIMULATION



#### REAL CERTIFICATION TESTS



Figure 2. Finite element analysis results and real pictures of certification tests.

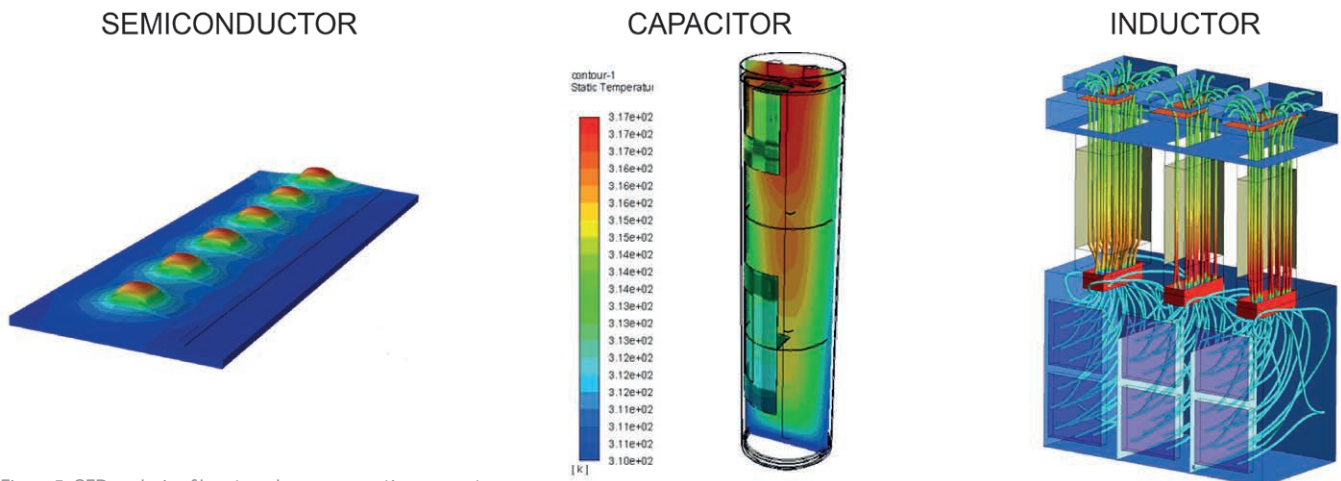


Figure 3. CFD analysis of Ingeteam's new generation converters.

the components can restrict the design of the wind turbine (the nacelle for example). In any case, independently of the cooling strategy, the management of the internal heat of the converter needs to be simulated so as to guarantee that all the internal components work inside the specification limits: Figure 3.

The new generation power converters from Ingeteam have gone through a complete ambient qualification process, in order to correlate the simulations and real test results. The main advantage of the correlation process is that the operation in

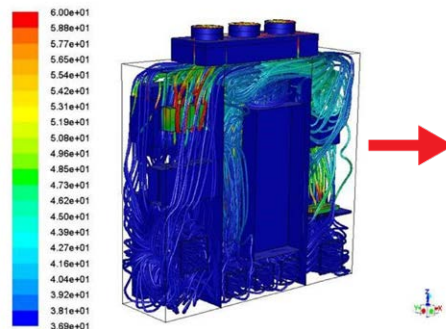


Figure 4. CFD analysis results and real pictures of certification tests in an in-house climatic chamber.

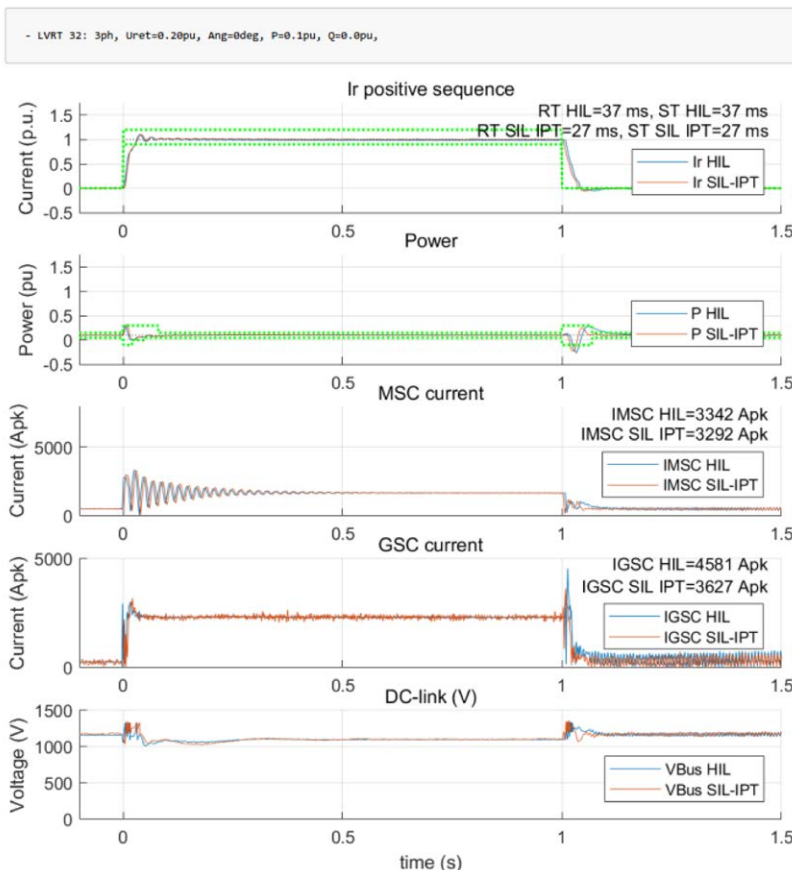


Figure 5. Ingeteam's dynamic response under SIL & HIL simulation for a three phase 20% retained voltage dip.

different locations, higher ambient temperature for example, or further power upgrades can be easily analyzed: Figure 4.

In order to always be able to propose the most optimal solution, Ingeteam offers a wide variety of ambient kits to adjust the converter design to the final location.

### High performance control techniques

Along with the HW design, control strategies are also necessary to assess the successful solution. Considering the newest grid codes and the different grid types that can be found all over the world, an extensive knowledge of the control algorithms that manage the power converter is necessary.

To do this, Ingeteam has developed advanced SIL and HIL models based on its wide experience with different grid types and events. These models reduce the qualification and certification time of the wind turbine and are in continuous evolution in order to replicate the real behavior of grids and wind turbines.

Regarding FRT compliance, Ingeteam has developed advanced control algorithms that give the converter the capability of injecting reactive current, to the grid in a very short time, keeping the active power of the turbine under control. In this way, Ingeteam's converters can fulfill the most

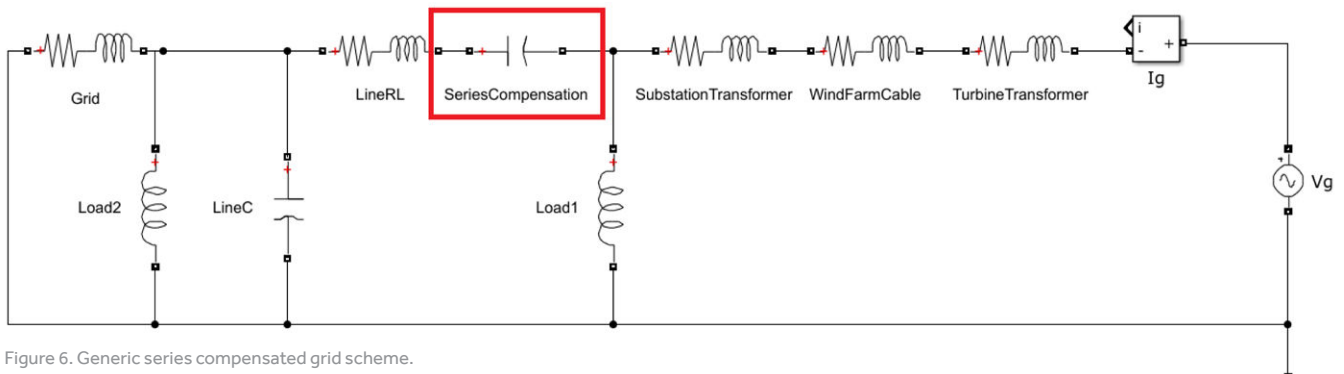


Figure 6. Generic series compensated grid scheme.

restrictive grid codes, both from the point of view of reactive current injection and also to control the active power required for manufacturer's drive train damping algorithms.

SIL and HIL simulations performed internally at Ingeteam facilities mean it's possible to analyze in detail the real behavior of the power converter: Figure 5

The above results show a response time under 30 ms with a settling time of less than 50 ms. The dynamic shown allows for the system to comply with the most severe grid codes, such as the German VDE 4120: Figure 6.

Another important field of study regarding grid integration is SSI/SSR (sub-synchronous interactions). Ingeteam's skills can provide the converter with the capability of coexisting with long series-compensated lines, where most DFIG turbines have sub-synchronous stability issues.

These kinds of grids have the particularity of having series capacitors connected to compensate the line. The inclusion of these capacitors generates zero impedance at certain frequencies that can generate grid resonances. This resonance/oscillation is characterized by a frequency value lower than the grid rate frequency, hence the sub-synchronous naming.

Standard dual current control used in most DFIG wind power converters used to be unstable in this kind of grids.

An excellent knowledge of control theory and grids has enabled Ingeteam to develop an algorithm, which provides DFIG turbines with the capability of coexisting with the most extreme series compensated lines.

Ingeteam's internal tools, based on full-control modeling and advance control theory, have made it possible to design full-frequency range stable control loops. The 2 charts in Figure 7, show an unstable control loop Bode diagram (top) and the advanced control loop Bode diagram designed by Ingeteam.

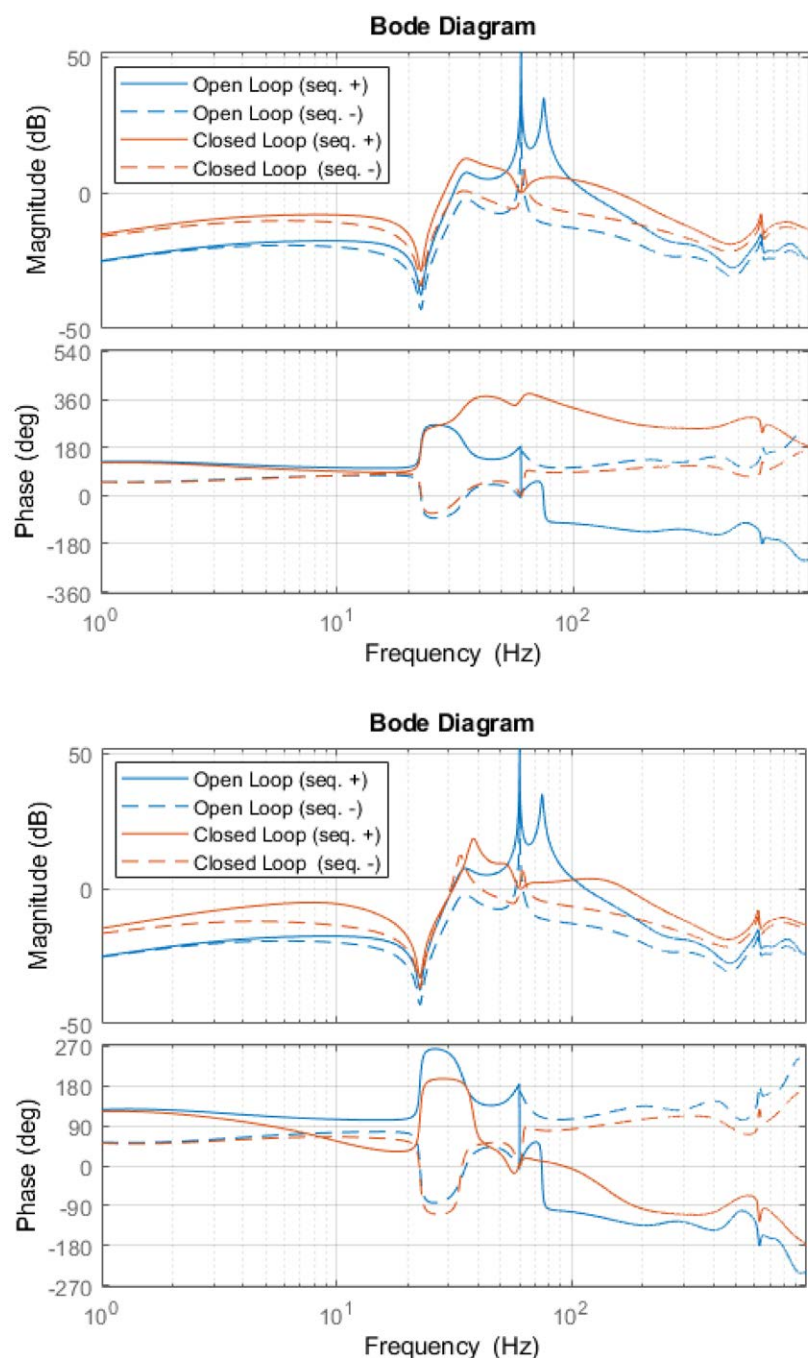


Figure 7. Unstable standard control loop Bode diagram vs IPT's advance control loop Bode diagram

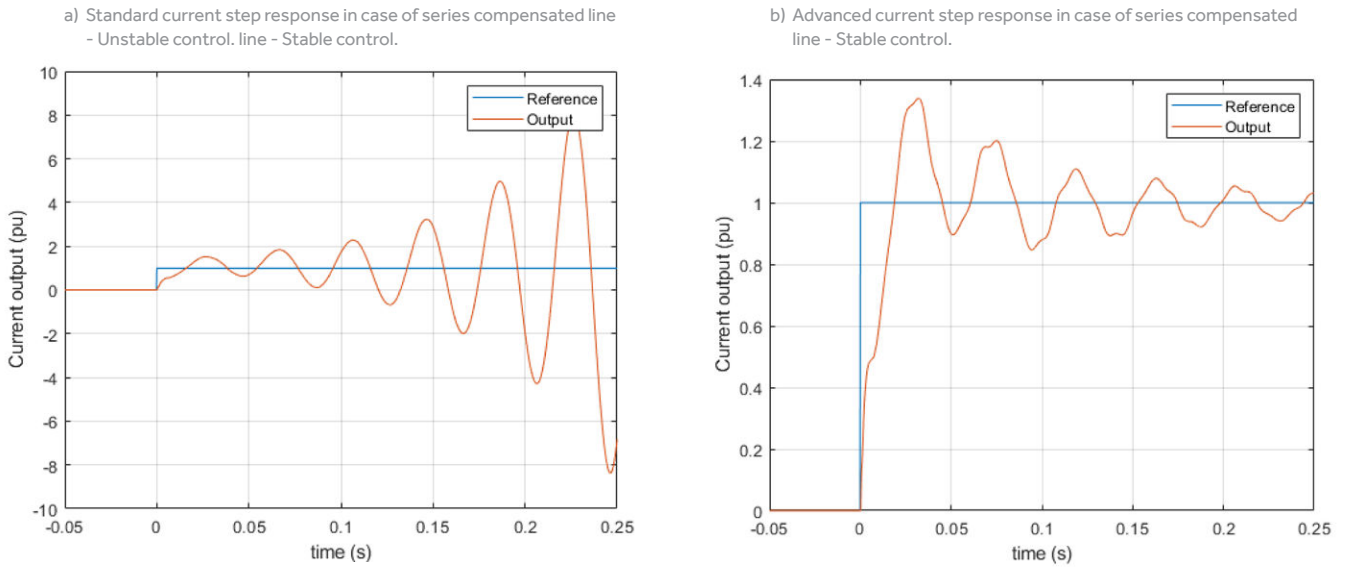


Figure 8. Current loop step response comparison in case of series compensated line.

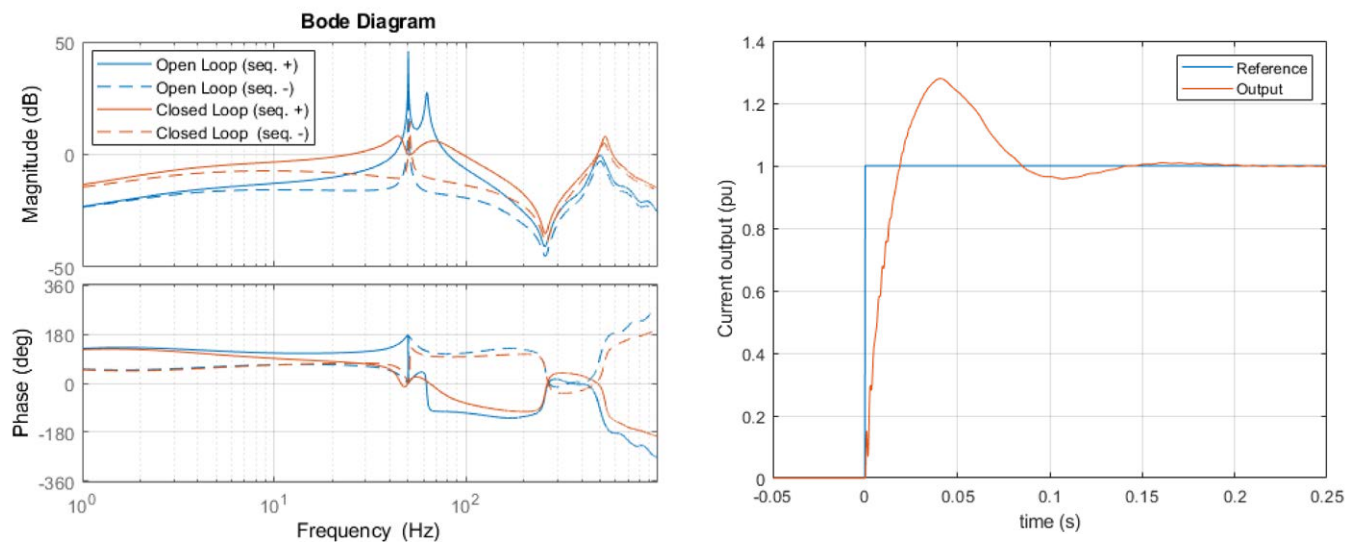


Figure 9. Advance control architecture for weak grids Bode diagram and current step response in case of SCR=1

With this advanced control loop, the unstable current step response is improved and can be considered as stable now: Figure 9.

Continuing with the control stability, another important topic is the operation of wind turbines connected to low SCR (short-circuit ratio) grids. As aforementioned, the advanced tools developed allow Ingeteam to design full-frequency range stable control loops. In case of low SCR, the instability problems use to appear from 500 Hz to 1500 Hz.

Ingeteam's advanced control allows wind turbines to be installed in weak grids with an equivalent SCR below 1. In the following picture, the Bode diagram of the current control loop (left) with a stable control architecture for weak grids and its step response (right) for an equivalent SCR of 1 are shown: Figure 9.

Overall, SIL & HIL platforms allow the qualification of control algorithms in a very precise way. Moreover, these platforms also allow the existing control algorithms to continuously evolve and adapt. Thus, able to respond rapidly to the customer's requirements with high quality standards.

#### Lowering wind energy's LCoE

In onshore applications, DFIG wind turbine topology is market leader thanks to a lower lifetime product cost that guarantees the most effective return on investment for most existing wind profiles.

Extensive knowledge and good techniques of HW and FW development and validation are a key factor to guarantee reliability and optimize cost in the High power DFIG wind turbine solution. Thanks to dedicated test benches, both HW and FW, Ingeteam fully

characterizes the power converter performance, allowing the extension of its capability up to its limits. The product RAMD metrics (MTBF & MTTR) are also evaluated in order to ensure the fulfillment of the high standards requirements of the wind industry.

All these elements, together with an extensive experience of DFIG application and partnership collaboration with all our customers, have led to optimized power converters for DFIG wind turbines beyond 6 MW. The new solutions offered by Ingeteam will drastically minimize the onsite validation and certification phase, reducing the time to market, and at the end, reducing the overall cost of the wind turbine.