Ingeteam

Offshore Wind Power Converter Product Range Up to 18 MW

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1. Introduction

During the last years, a fast development and huge increase in the amount of power generation plants is being produced, among which wind is one of the most widely used renewable energies.

In this sense, it is expected that offshore wind turbines will grow exponentially in the coming years due to the good wind conditions (much stronger and more constant wind comparing to onshore sites) thus increasing the energy harvest.

Nowadays offshore wind farms up to 13MW are in operation and it is expected that the power will continue increasing sharply, with the aim of producing solutions with optimized cost, high efficiency, easy maintainability and improved reliability.

One of main electrical drive train topologies is based on two electrically independent connections, one per conversion line.

This topology provides the benefit of increasing the availability of the turbine due to the redundancy of the power converter, which is a key factor in offshore market as increases the energy yield and the return of the investment.

Ingeteam´s Medium Voltage Power Converter product range up to 18 MW covers all the requirements of the future applications:

- Operation under harsh environments.
- Optimized basic power module for high efficiency operation and easy maintenance.
- Distributed control topology for managing different conversion lines.
- State-of-the-art converter control algorithms and dynamics.

2. Power converter product range overview

During the last years, Ingeteam has been developing a product range for high power wind turbines composed by Basic Power Modules (BPM) based on HV IGBTs.

As a first generation, the converter design reaches a power capability of 12MW by a 3L- Neutral Point Clamped (NPC) topology based on HV IGBTs of 1000 A.

Later, with no external changes in the converter design, the power capability of the product was increased up to 15MW. For that purpose, an evolution of the topology of the BPM was performed changing to Active Neutral-Point Clamped (ANPC), which replaces the clamp diodes of the 3L-NPC by active switches based on the same semiconductor. This provides an optimal distribution of the power losses, the junction temperature of the switches composing the inverter becomes the most similar possible and therefore the power capability of the converter can be increased.

In 2024, the capability of the INGECON® WIND FULL CONVERTER will reach 18 MW. This will be feasible with minimum design changes, replacing the HV IGBTs of 1000A by the 1500A reference.

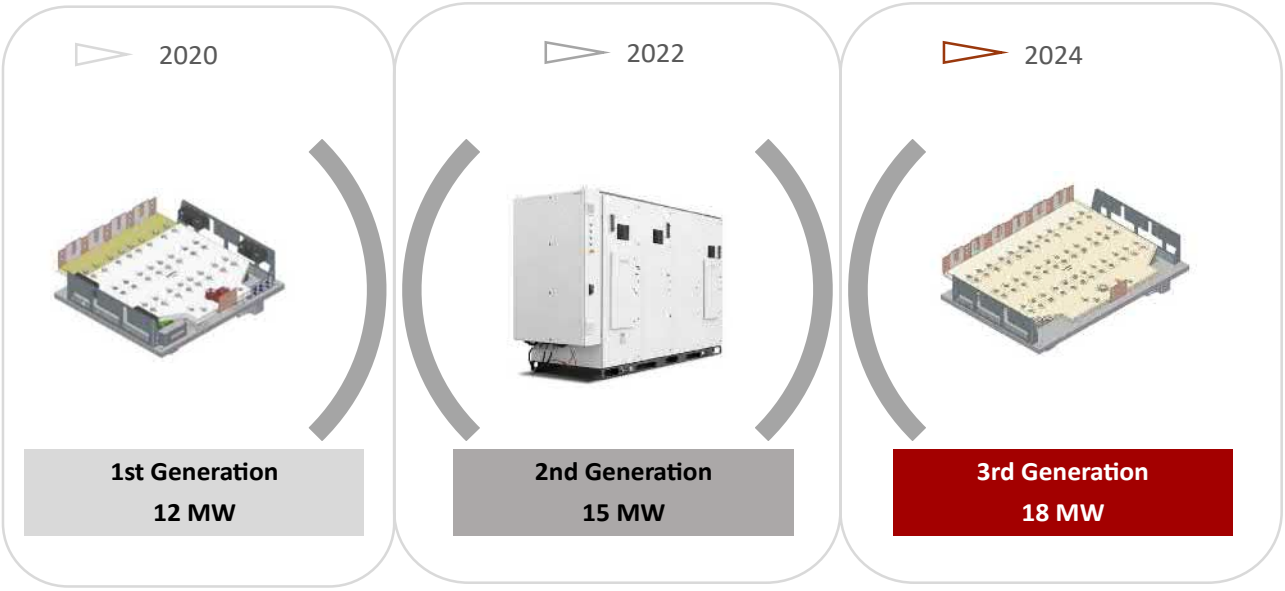

Figure. 1. INGECON WIND FULL CONVERTER product range overview

The developed Medium Voltage Power Converter product range is able to reach up to 18 MW by parallelizing two conversion lines (CL). The new product range complies with the strictest operation conditions (mechanical, electrical and ambient) even in the worst grid condition cases. Ingeteam has developed the control algorithms of its full power product range to guarantee the fulfilment of the most demanding grid codes together with optimized modulation techniques to fulfil the power quality standards demanded by the market.

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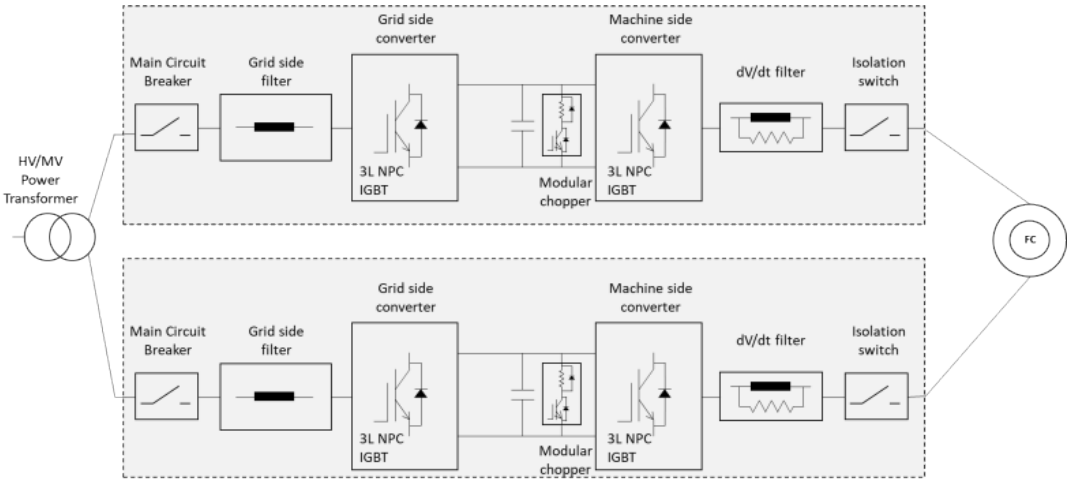

Figure. 2. Simplified electrical diagram of the Power Converter based on two conversion lines

Figure. 3. Conversion line design

This medium voltage Power Converter product range has been especially designed for the offshore market with a fully enclosed cabinet that guarantees the safe operation of the converter even in harsh environments.

The following table summarizes the main characteristics of the Power Converter product range:

Parameter	**12MW to 15MW**	**Up to 18MW**
Rated voltage	3300 V	
Rated current	3200 A_{RMS}	4000 A_{RMS}
Grid side frequency	50/60Hz	
Rated machine side frequency	> 7Hz	
Efficiency (at rated power)	> 98%	
Cooling	Full Water Cooled	
Dimension (per CL WxDxH)	3200x1200x2350 mm	4200x1200x2350 mm

Table 1. Main characteristics of the Power Converter

With efficiencies higher than >98% at rated operating conditions, the proposed solution significantly minimizes the production losses of the wind turbine.

The design of the converter offers maintenance-friendly characteristics with front access and removable key components that directly contribute to minimize the OPEX related to the service of the wind turbine, therefore optimizing the LCoE of the product.

Ingeteam has developed the control algorithms of its full power converters to guarantee the fulfilment of the most demanding grid codes together with optimized modulation techniques to fulfil the power quality standards demanded by the market and specific customers.

3. Basic Power Module (BPM)

The INGECON® WIND FULL POWER CONVERTER product range is a continuous and evolutionary design based on HV IGBT semiconductors technology.

The evolution of the HV IGBT during the last years has allowed to create a product range that increases the power density of the converters design by minimum design changes giving high competitiveness comparing to other solutions on the market.

The power conversion unit is composed of six phase BPMs and one brake chopper BPM.
In the next figure, the assembly of the BPMs and a single-phase BPM can be observed.

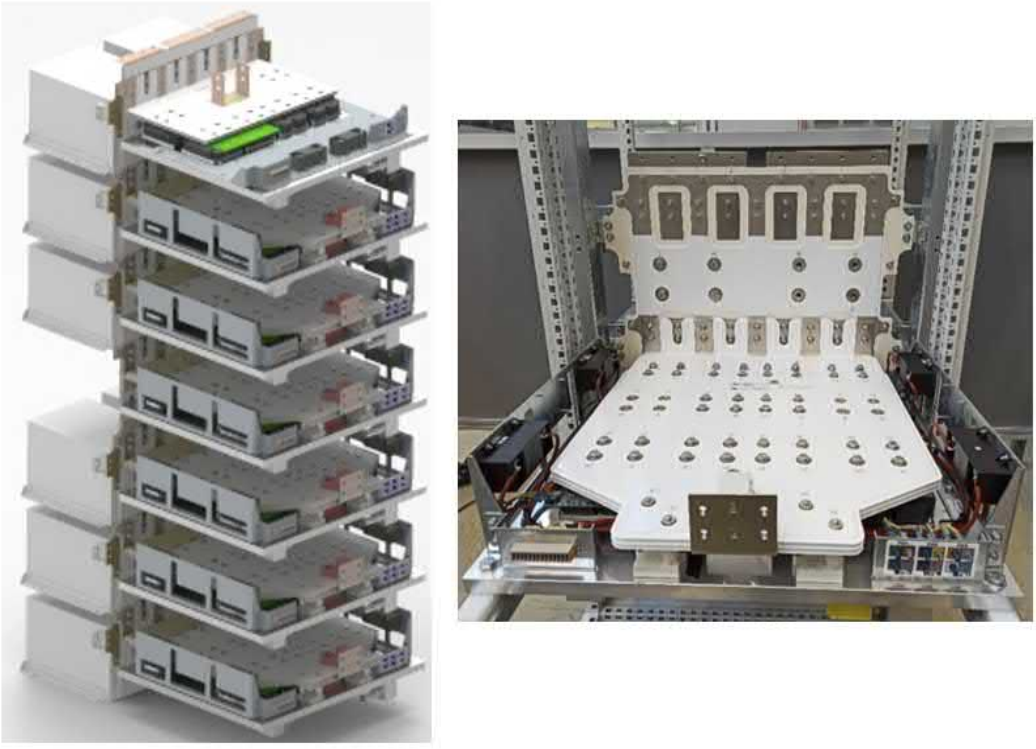

Figure. 4. Assembly of the BPMs and a single-phase BPM

Within Ingeteam, the HV IGBT is a widely used technology that has been proven during years of operation in harsh environments such as traction, marine propulsions and dredging applications.

The assembly of the HV IGBT does not need any additional tooling which eases the mounting process of the BPMs and as the package of the semiconductor includes insulation to the cooling circuit there is no need of deionized water resulting in an optimization of the cooling system.

The main characteristics of the BPMs are:

Description	Value
Topology	3L
Output voltage	3.3 kV
Semiconductor voltage class	4.5 kV
Cooling	Liquid / Forced air

Table 2. Main characteristics of the BPMs

One of the key components to assure a good current balance and low stray inductance is the busbar. Busbars have been designed using Maxwell for electrical optimization and Fluent for thermal optimization.
In the following pictures, simulation results can be observed:

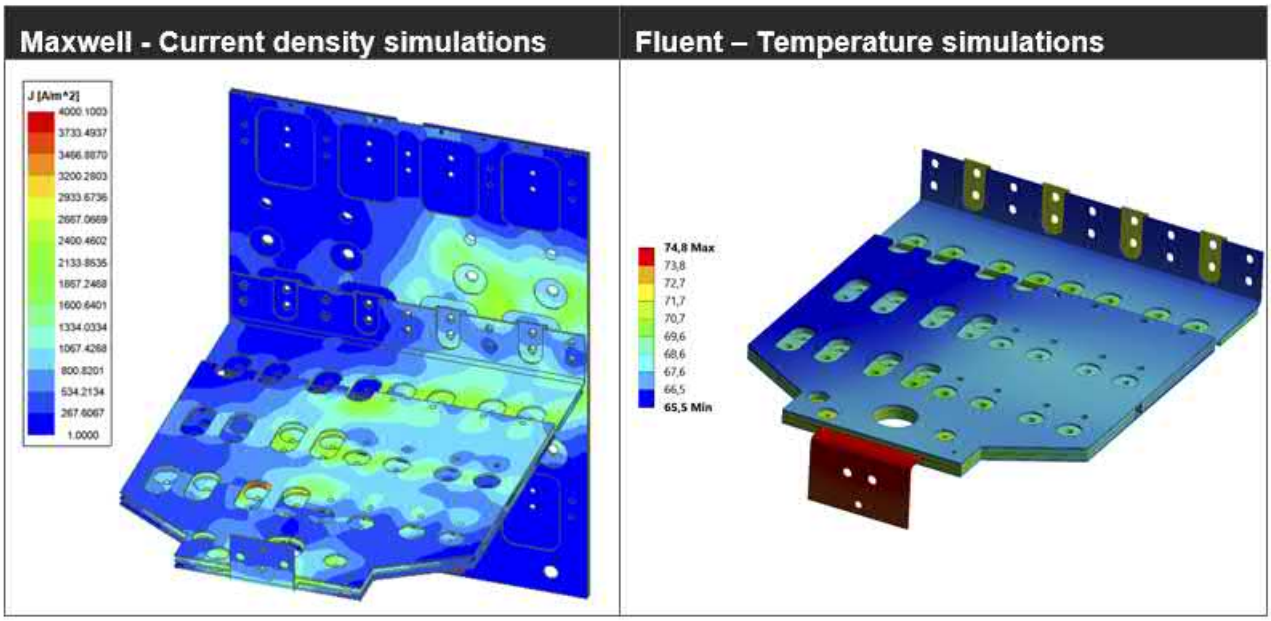

Figure. 5. Current density and temperature simulation results

The real benefit of the busbar simulations can be seen in switching waveforms. The next picture shows a double pulse test switching waveform at nominal DC-Link voltage, nominal junction temperature and 2 times nominal collector current.

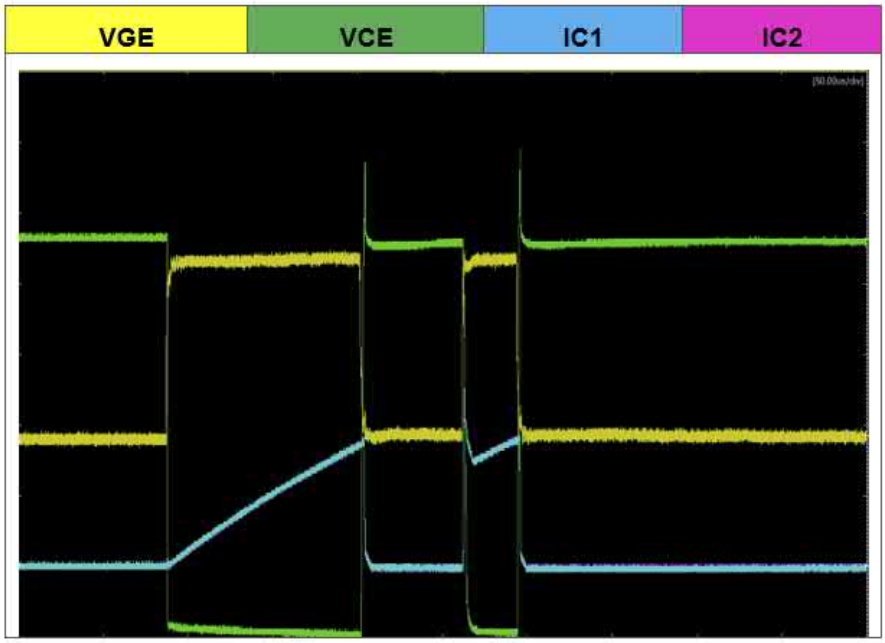

Figure. 6. Double pulse test switching waveform at nominal

The next figure shows more in detail switch on and off instants.

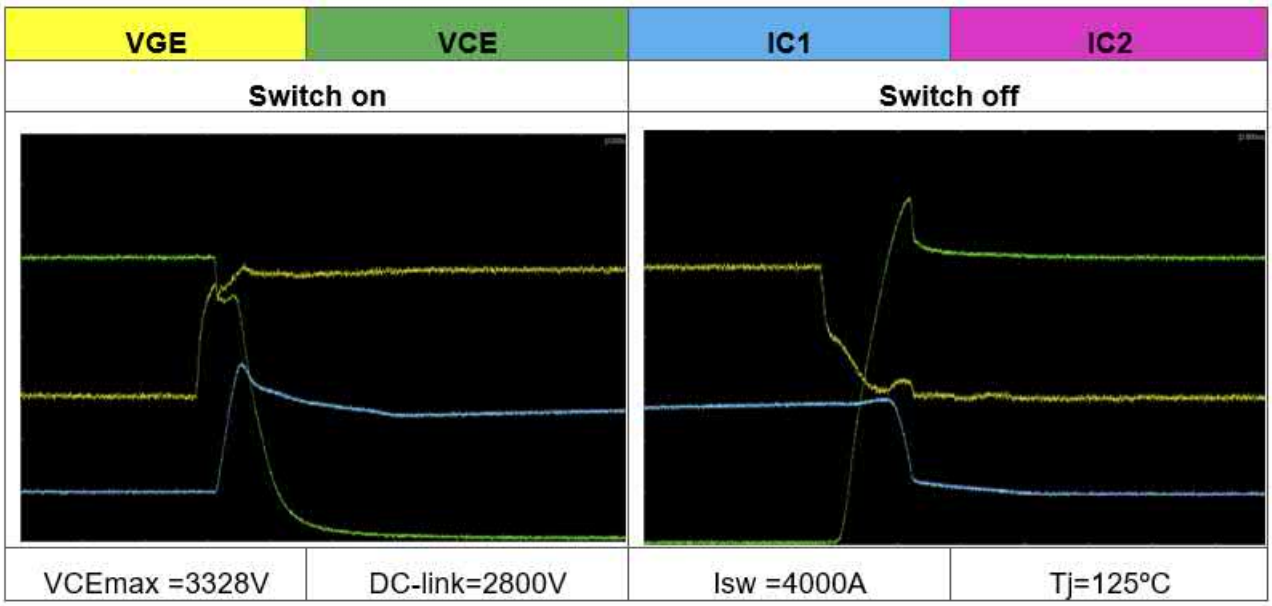

Figure. 7. Double pulse test, switch-on and switch-off details

As it can be seen, current balance is very good and low overvoltage can be observed.

The semiconductor thermal behaviour is also analysed. Thermal characterization of the complete cooling system is done in order to estimate the junction temperature, checking it's under the maximum allowable value.

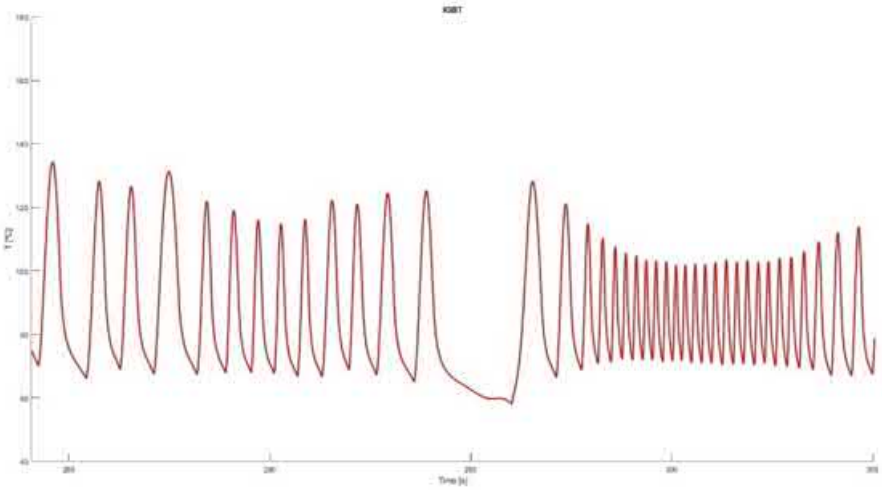

Figure. 8. Junction temperature of a mission profile (zoom in)

Based on typical mission profiles, lifetime expectancy calculations are done. This let's check lifetime expectancy requirements are fulfilled.

4. Control architecture

Control Electronics for this converter are based on a Distributed Control topology which is composed of two main components:

- Control Converter Unit.
- Power Management Module.

Distributed Control Electronics allow the operation of the conversion lines from a distributed perspective, allowing to manage redundancy under faulty conditions and thus maximizing availability of the turbine.

Converter Control Unit (CCU)

The Converter Control Unit (CCU) is located in the control cabinet.

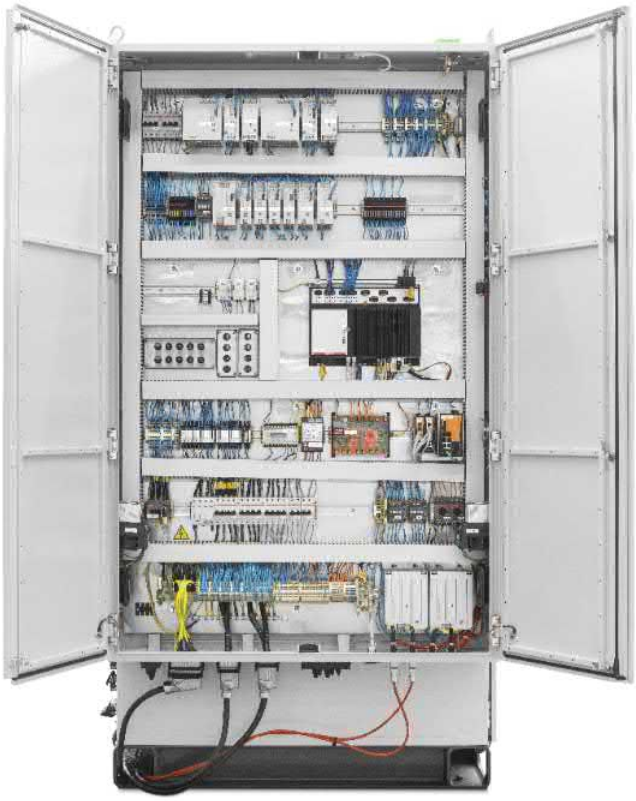

Figure. 9. Converter Control Unit

Soft Real Time Logic Tasks (cycle above 1ms) and Hard Real Time Regulation Tasks (cycle from 80us to 1ms) for both conversion lines are executed in two specific and independent processing cores within this CCU.

The CCU is the only access-point to the converter for any external communication link, providing a fieldbus slave node adequate to the customer needs, OPC-UA server and web-server for remote monitoring and control. OPC-UA and web servers have been designed with cybersecurity as a target.

Moreover, the CCU provide fieldbus master nodes to be able to control and monitor Intelligent Embedded Devices (IEDs) inside the converter, which is useful for IED prognosis.

The CCU communicates with Power Management Modules (PMMs) through fibre optic links in order to avoid electromagnetic issues between control cabinet and power conversion line cabinets. Ingeteam's proprietary C2Plink protocol, specifically designed to get the optimal efficiency in terms of bandwidth and latency, is used.

Power Management Module (PMM)

Power Management Modules (PMMs) are located within power conversion line cabinets. Each power conversion line cabinet includes two PMMs.

Figure. 10. Power Management Modules

PMMs of each power line cabinet are mainly in charge of:

1. Digitalizing electrical measures of the power conversion line in order to send them upwards to the CCU through the C2Plink.

2. Generating trigger signals for IGBT gate drivers based on the orders received from the CCU through the C2Plink.

Last but not least, the PMM includes protection logics and Fault-Ride-Through Logics in order to provide very fast local actuation when needed. These PMM logics could be eventually updated remotely if needed.

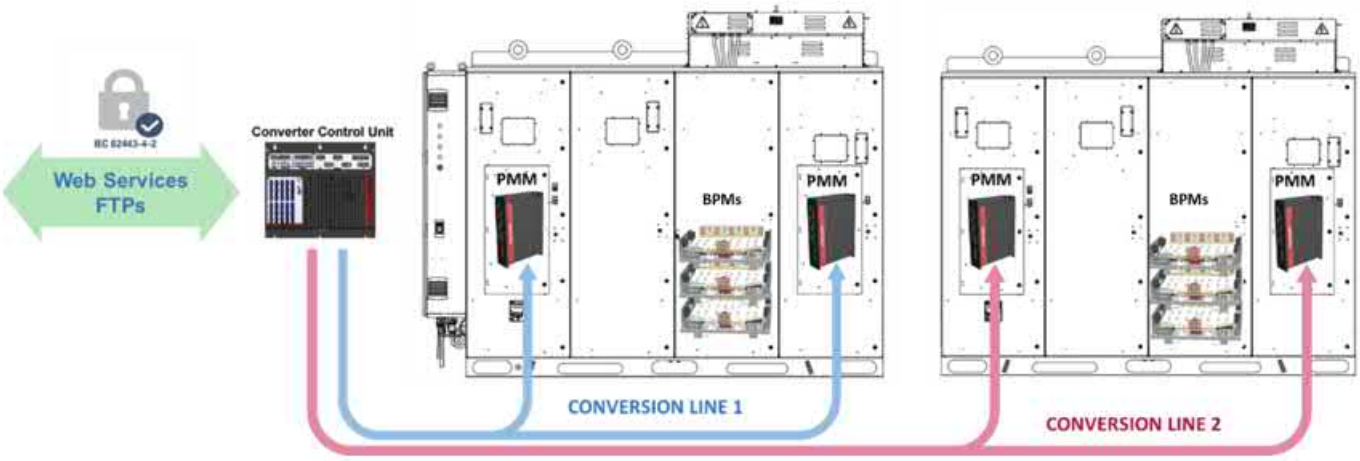

Figure. 11. Control Architecture

5. Converter control and dynamics

The main functionalities of the converter control are:

- Start-up from grid / start-up from machine
- Current controller
- Torque/Power controller
- Stator voltage controller
- Reactive power controller
- Generator (production) mode
- Motor (positioning) mode
- FRT control. Grid Code compliance

With all the previous design criteria in mind, the converter control must be able to comply with the dynamic requirements both in the Machine Side Converter (torque response) and in the Grid Side Converter (power response, grid code dynamic requirements compliance).

An overview of the dynamic capabilities in production mode are shown as an example.

Looking at the Machine Side Converter, a step power response of 50ms of settling time can be achieved, where the overshoot can be tuned to meet application demands.

Response time	< 0.07 s
Setting time	< 0.08 s
Maximum peak-to-peak ripple	2% of the rated torque

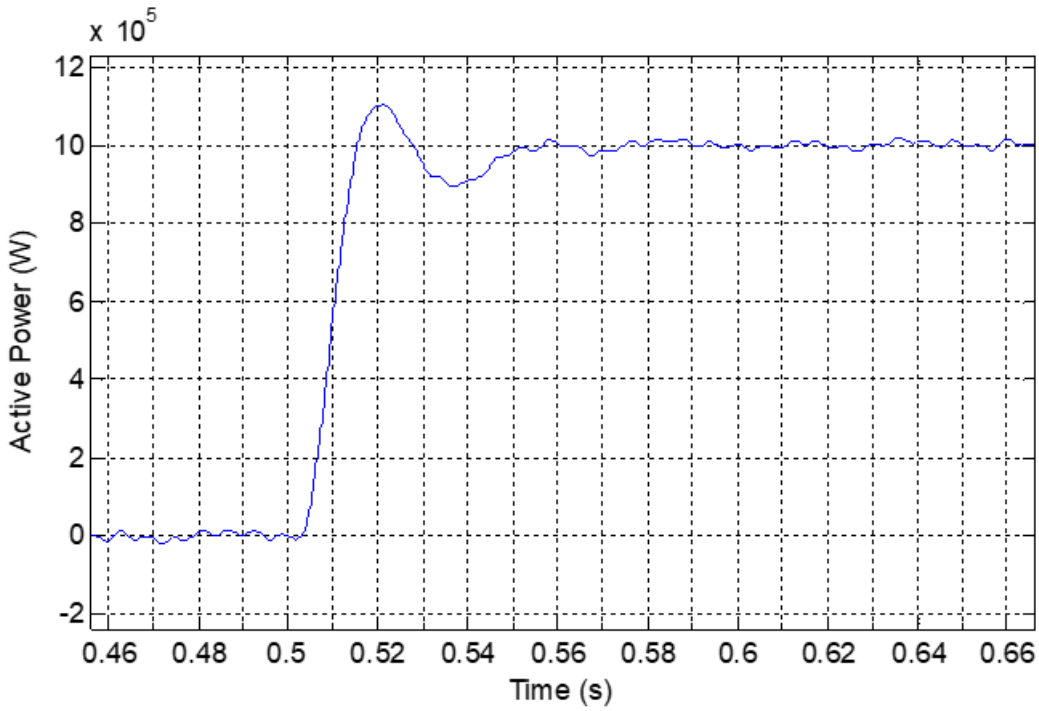

Figure. 12. Power step response for a 1MW step with 10% allowed overshoot

The installation of a speed/angle encoder is not mandatory, as this response is achieved both with speed sensor and in a sensorless setup.

The reactive power response, from the Grid Side Converter controller, is tuned according to the application needs.

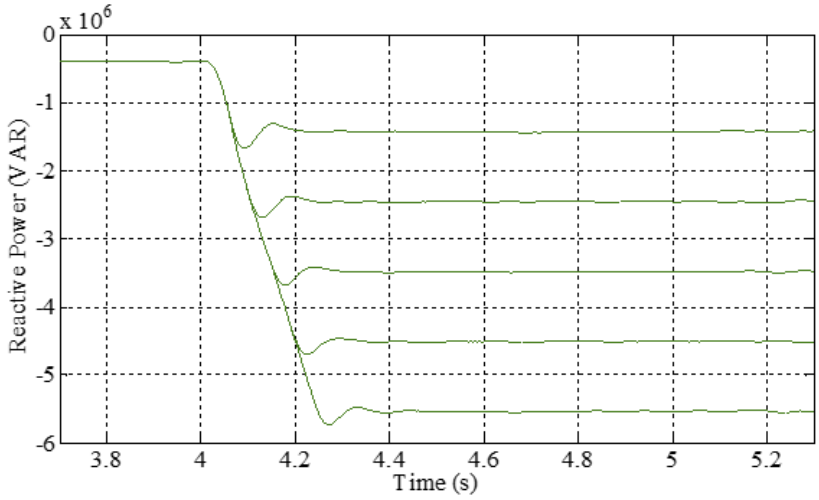

Figure. 13. Reactive power response to different power levels. Ramped response

The default behaviour of the converter is adjusted to cope with weak grids down to 1.5 Short Circuit Ratio (the standard value is SCR=3).

Grid Code compliance is ensured by the FRT control strategy both in positive and negative sequences, in order to cope with the most demanding requirements.

Finally, it must be considered that Ingeteam has developed the control algorithms of its full power converters to guarantee the fulfilment of the most demanding grid codes together with optimized modulation techniques to fulfil the power quality standards demanded by the market (FRT, low SCR grids). The control algorithms have been developed under SIL simulation and HIL validation before test bench validation and commissioning.

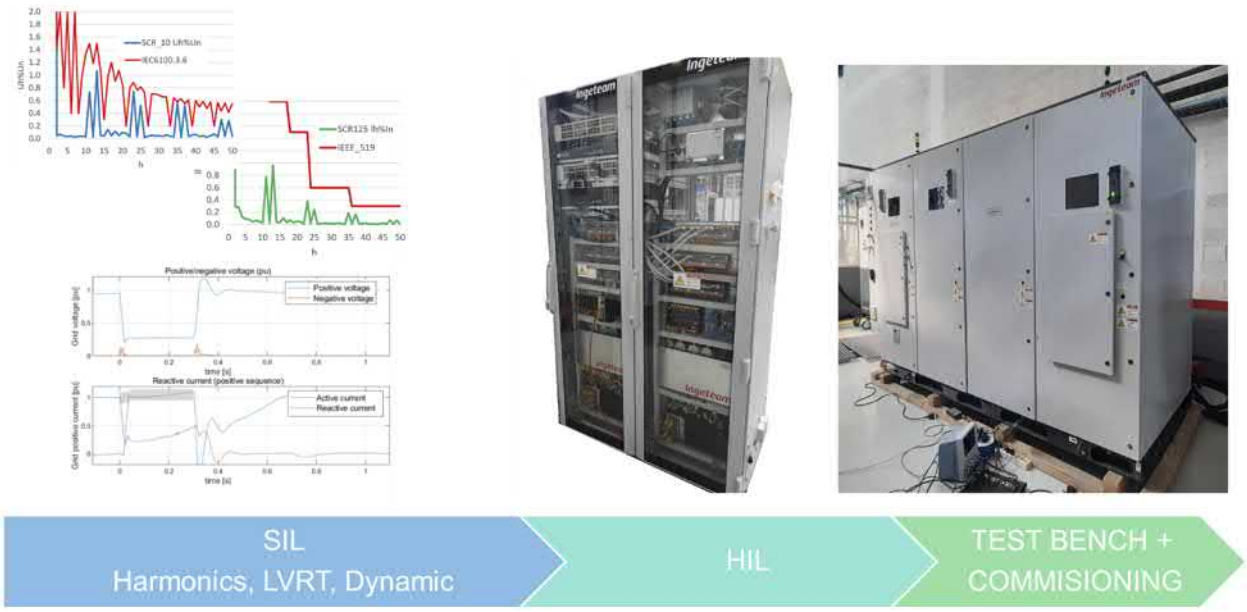

Figure. 14. Control Algorithms: Model Basic Design

6. Conclusions

During the last years, Ingeteam has been developing the INGECON® WIND FULL POWER CONVERTER product range for high power wind turbines composed of Basic Power Modules (BPM) based on HV IGBTs.

The evolution of the HV IGBT has allowed to create a product range that increases the power density of the converters design by minimum design changes giving high competitiveness comparing to other solutions in the market.

The product range has been especially designed for the offshore market with a fully enclosed cabinet that guarantees the safe operation of the converter even in harsh environments.

The INGECON® WIND FULL POWER CONVERTER product range contributes to lowering the LCOE of 18 MW offshore wind turbines by maximizing reliability and minimizing the maintenance requirements of its key components. It offers maintenance-friendly characteristics with front access and removable key components leading to lower operational expenditures.

With efficiencies higher than >98% at rated operating conditions, the INGECON® WIND FULL CONVERTER MV product range significantly lowers the production losses of the wind turbine.

7. Author

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