ABB PROPULSION CONTROL

Ice Mode Encounters in Kara Sea onboard Christophe de Margerie

ABB is happy to report that the Ice Mode function, which Generations covered in its 2016 Connectivity issue, has now been successfully trialled in ARC-7 ice conditions.

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The Christophe de Margerie (DSME H2418), the first of the series of Yamal ice-class LNG carriers with Azipod®-based electric propulsion, conducted ice trials in the winter of 2016/2017. Two of the authors of this article, Bo-Won Lee and Michal Robenek, were onboard in the ice trial support function, as the specialists for propulsion control and ACS 6000 drives respectively. During the trials, the Ice Mode function successfully handled the customer and owner requirements. The concept proposed by DSME and ABB was proven with flying colours, as the Ice Mode functionality added to the ABB Propulsion Control Units (PCU) used boil-off gas as the prime mover fuel for maximum ice-breaking effect.

The Vessel

The Christophe de Margerie, in Figure 1, is the first of the Yamalmax class of LNG carriers designed and built to ship liquefied natural gas from the newly constructed port of Sabetta, built to service the Yamal gas fields of northern Russia. It is owned and operated by the Russian company Sovcomflot, and is the first in the line of 15 ships to be built according to the requirements of the Yamal project. The vessel, previously Daewoo Shipbuilding and Marine Engineering (DSME) hull number 2418, is registered under the IMO number 9737187. It is 299 m long, with the beam of 50 m, draft of 10.4 m, gross tonnage of 128 806 t and summer deadweight tonnage of 96 779 t. Christophe de Margerie is capable of carrying 172 600 m3 of liquefied natural gas across the High Arctic route to the markets of Korea, Japan, and China. More importantly for the Ice Mode function, the vessel is an ice-breaking design up to ARC-7 specifications, capable of breaking 2.1 m thick Arctic ice. The vessel breaks the ice while sailing stern-first (see Figure 7), using ABB Azipods® to create under-pressure below the ice-sheet, which thus loses support and breaks off into the low-pressure flume. Thereafter, broken off pieces of the ice sheet are further milled by the Azipods® and ultimately expelled to the sides of the ship, facilitated by the curves and reinforcement of the ice-breaking stern.

Propulsion Setup

Steaming and ice-breaking are both the function of the ship's main electrical propulsion system, comprising three ice-breaking Azipod® VI thrusters rated at 15 MW for the total propulsion power of 45 MW. The thruster drives, three of ABB's top-segment ACS 6000 lineups, are supplied from two symmetric power supply and distribution sections, each characterised by a set of three ABB generators, two rated at 12.5 MVA, and one each of 9.4 MVA, according to the SLD in Figure 2.

Figure 1 (over): SCF – Sovcomflot IMO 9737187 Christophe de Margerie (previously DSME H2418), the world's first Yamalmax electrical propulsion LNG carrier with ARC-7 ice class

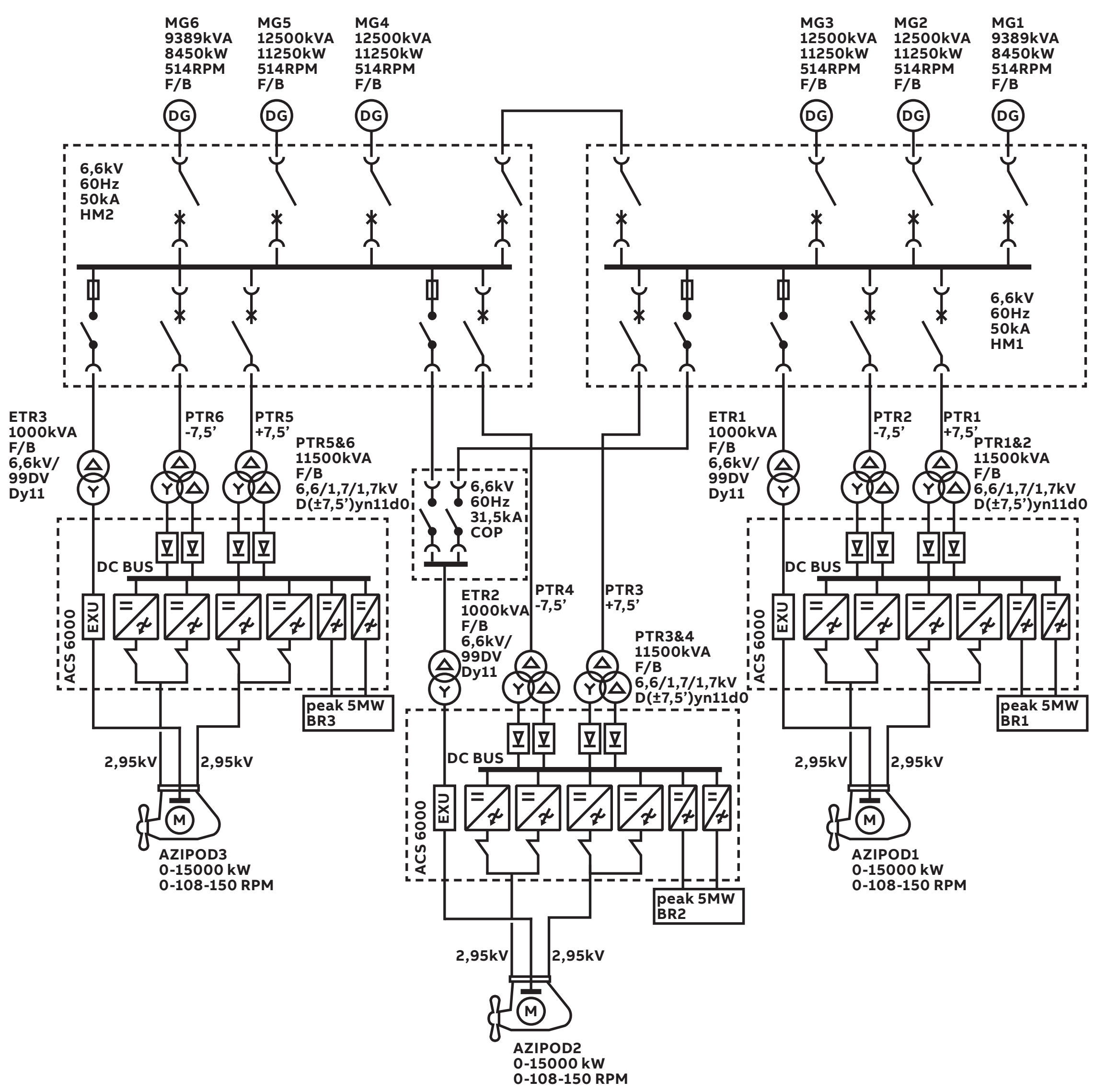

Figure 2: Single-line diagram of Yamalmax LNG carriers

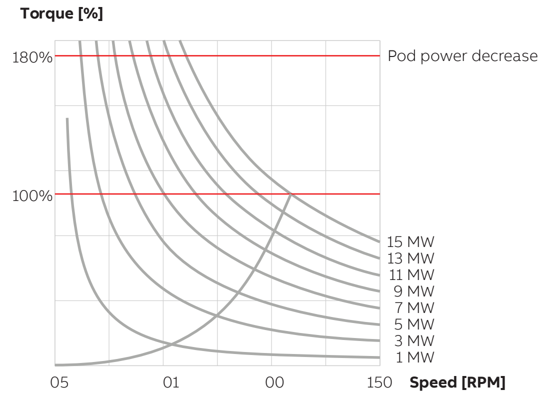

Figure 3: The loading curves for the Azipods of Yamalmax LNG carriers

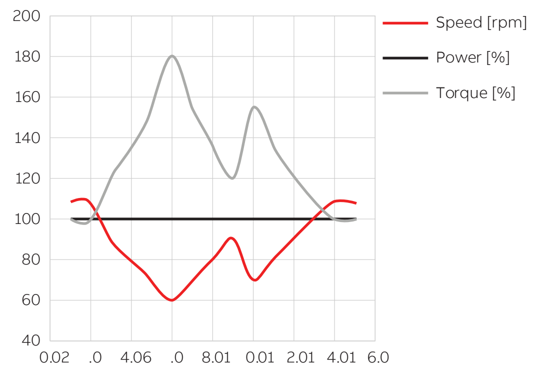

Figure 4: Stability of power principle, with torque necessary for equilibrium under 180 % nominal

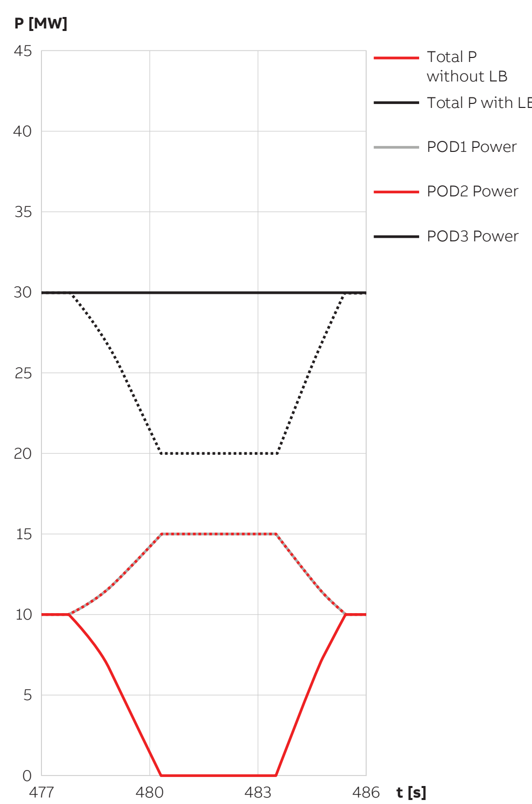

Figure 5: Principle of the Ice Mode function that boosts the load of active pods, taking over from a stalled one

The two side pods are individually fed from the respective sections of the power system, whereas the middle pod is fed from a dual supply of both sections. This means that in the case of failure of one section, power (albeit decreased) is still available to the middle pod. Accordingly, in the failure scenario of either section, two pods are available, guaranteeing vessel manoeuvrability.

Ice-Breaking Considerations

Especially important for ice-breaking (as well as crash stop) operations are the three installed breaking resistor units (BRUs) rated at 5 MW peak power, represented by BR1, 2, and 3 in Figure 2. Another important feature that facilitates ice-breaking in Christophe de Margerie and other forthcoming Yamalmax LNG carriers, is that the ACS 6000 drives for this project have been parameterised, tested, and commissioned with 180% over-torque capabilities, as noted in Figure 3. This is 30% more than the 150% over-torque capability usually provided by ABB for ice-class vessels.

The over-torque allows the Azipods to deliver sustained torque in conditions of a stable power command from the bridge, but with speed of revolution of the propellers widely varying and jittering due to mechanical milling and grinding of the ice sheet. In such unsteady conditions, the instantaneous torque command channel is continually updated on the ACS 6000 drive from the propulsion control units (PCUs). The PCUs are dedicated ABB controllers that implement and execute all the generic and specific propulsion control functions, including the Ice Mode function. The cyclical and instantaneous calculation is always proportional to the power commanded by the levers on the bridge, ice-breaking bridge, wings, or ECR –and inversely proportional to the instantaneous speed of revolution of the propeller. As the speed of revolution decreases due to friction with ice during milling and breaking, the torque necessary to break through the ice and maintain continuous rpm operation increases. In that way, the mechanical power provided by the propeller remains constant even in cases of dropping speed of revolution, as displayed in Figure 4.

In the cases where, at a required amount of power from the commanding levers, the speed of revolution of the propeller drops below a critical value

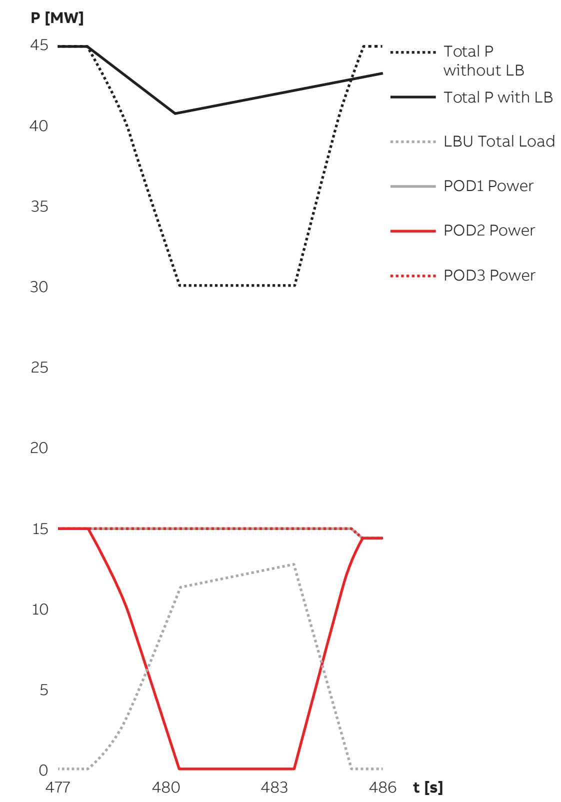

Figure 6: Principle of the Ice Mode function that boosts load by activating the breaking resistors, and anticipates restoration of nominal conditions by throttling up the prime movers during stall-out

given as the respective power curves intersect with the 180% horizontal line on Figure 3, the regime of operation changes. The drive will cap the torque at 180% nominal. In such cases, precipitous and sudden dips of the load, in proportion to the variability of the speed of revolution, will be observed on the electrical network. Governors of the prime movers will seek to throttle down the gas-fired engines according to their rpm feedbacks. If the precipitousness of the rpm drop is sufficient that, in the proportional reaction of the governors, the throttling down will exceed, in its rate, the achievable elasticity of the throttle when fired by boil-off gas, the engine control unit will switch the fuel to the more elastic marine diesel. If even the marine diesel dynamics of the prime mover are not able to satisfy the dropping rate of throttling, the frequency of the network will grow unchecked and safeguards will ultimately react to black-out the offending section, or the entire network.

The Ice Mode Function

Even in the cases where throttling down with diesel-fired prime movers would be sufficiently fast to accommodate the rpm drop, this is an economically inefficient way of operating the Yamalmax LNG carriers. If possible, the ice-breaking transit should be made on boil-off gas fuelled prime movers, which are of thermodynamic necessity more sluggish in their throttle response. To ameliorate the gap between the possibly very dynamic propeller rpm response to ice-milling, and a sluggish throttle response of gas-fired engines, the Ice Mode function dynamically redistributes or boosts the electrical load to equilibrate the electrical network.

The Ice Mode function is based on cross-connectedness of the PCUs supervising and controlling the three propulsion sections in the bottom part of the SLD presented in Figure 2. In that way, the heavy loads respond as a system, offsetting in an optimal way three principle modes of equilibrating the network:

1. Maximum amount of generation excess is removed by throttling down the prime movers at the maximum rate allowed by the boil-off gas thermodynamic process.
2. The remaining excess is picked up by the spare capacity (the difference between the commanded power on the lever and the maximum power rating) of the Azipods® not experiencing a loss of power, at the maximum rate allowed by the ACS 6000 drive.
3. The remaining excess is picked up by switching in the breaking resistors BR1, 2, and 3, if they are available due to possible temperature-based interlock. This function of the Ice Mode is called the Load Bank function.

Additionally, the design of the Ice Mode Load Bank function takes explicit care of the disparity between responsiveness in throttle-down to throttle-up when operating internal combustion engines (regardless of fuel). Once the load on the ice-stalled pod crosses (and pans out at) zero, the Ice Mode proactively throttles up the prime movers, anticipating unlocking of the stalled pod and a resumption of operations according to the power lever settings. The Ice Mode throttles up the prime movers indirectly, by intentionally displacing the electrical network from its equilibrium, dictating a further ramped increase of load on either the breaking resistors, or the spare-capacity pods. This causes the governors of the

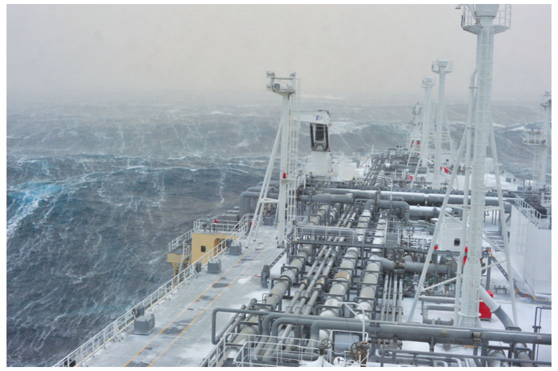

Figure 7: Rough sailing conditions are expected for Christophe de Margerie and sister Yamalmax LNG carriers, even when not conducting ice-breaking operations

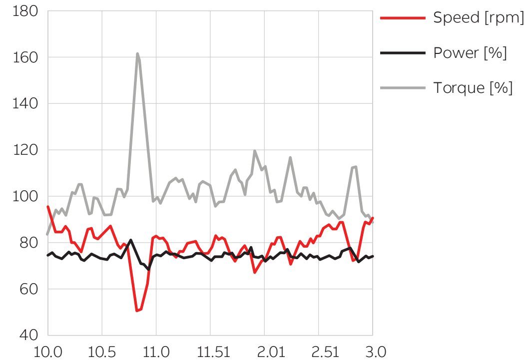

Figure 8: Stability of power in the case of speed of revolution dips due to ice-milling, where torque necessary for equilibrium is under 180% nominal, onboard the Christophe de Margerie

Figure 9: Ice-breaking conditions faced by Christophe de Margerie on its Kara Sea Ice Trials

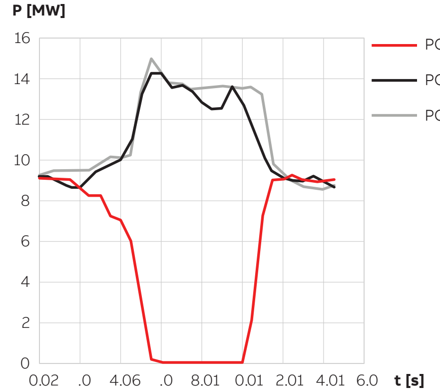

Figure 10: Power boosting function in practice onboard Christophe de Margerie during Ice Trials in the Kara Sea (cf. Figure 4)

prime movers to respond to the falling network frequency by ramping up the engines. The ramp-up regime stops when either the nominal amount of generation is achieved, even in the stalled pod configuration, or the pods re-start propeller rotation and conditions on the electrical network are restored to the original levers' settings.

The principle of load boost on pods other than the one stalling in ice is displayed in Figure 5. The principle of load boost by a breaking resistor, i.e. the Load Bank function, together with the proactive ramp up at power zero-crossing of the stalling pod, is displayed in Figure 6.

The Ice Trials of Christophe de Margerie
Christophe de Margerie sailed out on its Ice Trial voyage on 2 February 2017, departing the Zebrugge LNG port, after loading its first cargo following the vessel's delivery from DSME. The vessel sailed with ice trial participants on board, from the shipyard and several important suppliers, in a variety of engineering support functions. After a few days at sea, in progressively more difficult conditions, see Figure 7, the vessel could start facing the sea ice after passing the northern promontory of Severny island and transitioning from the Barents to the Kara Sea.

Testing The System And Ice Mode Functions
With respect to the described over-torque capability of the installed ACS 6000 drives, there are several implementation obstacles to achieving the perfect equilibrium in the principle displayed in Figure 4. Such obstacles are e.g. processing delays of the speed feedback and calculation blocks for the new torque reference, communication delays between the PCU and the drive line-up, and a selection of measurement imperfections such as LSB jitter, or ADC imprecisions. However, even taking these into consideration, and due to ABB's propulsion control algorithms, a high quality stability of power expended (i.e. electrical load on the network) was still achieved during the Ice Trial, according to Figure 10.

With regard to the Ice Mode functions, these were severely tested by the ice-breaking conditions, as visible in Figure 9. We have selected a number of representative cases that display the principles designed for and depicted in Figures 5 and 6.

In the instance of the power boost function, a representative logged trend in Figure 10 shows the starboard Azipod® stalling in heavy ice even with full over-torque applied. As a result, the propulsion power rapidly decreases to near 0 MW from the lever rating of ca. 9 MW. The Ice Mode function implemented across the three PCUs responsible for the three pods immediately kicked in, assuring that the lost load was reclaimed by boosting the load on the central and port Azipod® equally. This resulted in ca. 4.5 MW boosted on each pod up from their lever settings of ca. 9 MW, meaning they were temporarily operating at near peak performance of 13.5 MW. Once the stalled propeller broke free of the heavy ice and the propulsion power started ramping back to the original power reference, the boosted pods proportionally released their boost down to their own references, equilibrating the network to its original conditions.

With respect to the breaking resistor boosting functions of the Ice Mode, the most severe stress-test came when the vessel penetrated a heavy ice ridge of ca. 500 m length, with 15 to 18 m ice sheet thickness. In these conditions, with all

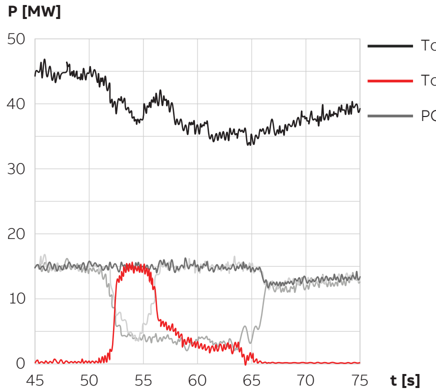

Figure 11: The Load Bank function in a severe stress-test onboard Christophe de Margerie during Ice Trials in the Kara Sea (cf. Figure 5)

Figure 12: ABB's Ice Trial personnel proudly completing the Christophe de Margerie 2017 Ice Trials with the first shipment of LNG cargo onboard

three Azipods® operating at peak performance of 15 MW in order to make any progress in milling ice, two pods simultaneously encountered heavy ice load, resulting in a total loss of 23 MW of propulsion power, as per Figure 11.

The Load Bank function coordinated all three networked PCUs, each in turn commanding the three breaking resistor banks BR1, 2, and 3, in a co-ordinated fashion, producing the aggregate dissipated power displayed in Figure 10. This response kept the total load variation (black line) appropriately low so that the ECUs of the dual-fuel engines could follow the variations while continuing to feed the engines boil-off gas, rather than switching over to marine diesel. No safeguards or interlock were activated, even during a cumulative loss of power of 23 MW for 3 seconds, continuing with the loss of 10 MW for the next 7 – 8 seconds after that, before returning to nominal operating conditions.

In conclusion, the authors, and the whole Technology and Engineering organisation at ABB Marine & Ports, were very proud to see an agile innovation provided to the customer within the scope of an ambitious delivery deadline, and tested for its mettle in such a harsh environment. Two of the authors, out of the group of four, who as a group conceptualised, designed, implemented, tested, commissioned, and trialled the Ice Mode function, were also on board and were able to testify to a smooth and failure-free operation of all the developed functions and installed hardware equipment. The ice trials were completed with ample spare time, after only six weeks. Michael Robenek and Bo-Won Lee, first and second from the right respectively, are understandably visibly relieved, satisfied, and proud in the group photo of ABB's complement onboard Christophe during the Ice Trials in Figure 12. ABB looks forward to the whole collection of 15 Yamalmax LNG carriers with ARC-7 ice-breaking capability, ultimately relying on high capacity ACS 6000 drives and the AC800 M PCU controllers running the Ice Mode, to provide uninterrupted, economical, and safe navigation on boil-off gas-fired engines the length of the Arctic route.

*ABB Ice Mode – Smart, connected, safe solutions for Arctic LNG
M. Barisic, B. Gundersen, M. Robenek, H. Knappskog
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