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Coming up in the next edition: **50 years of robotics**

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EDITORIAL

Navigating efficiency

Dear Reader,

I am proud to welcome you to the first edition of ABB Review to be published in my tenure as CEO.

Humanity is facing challenges on a scale never experienced before, threatening the livability of our planet. Fortunately, many of these challenges can be overcome by engineering – be it through the integration of fossil-free energy, through energy efficiency, through circularity and conservation of resources, or through higher productivity thanks to AI-driven insights and decisions.

For 110 years now, ABB Review has reported from the forefront of research and development. In this edition, we present Dynafin™, a new maritime propulsion system enabling energy savings of up to 22 percent compared to the propeller. Other breakthroughs include electrification of mining and advanced sensors in papermaking.

Discover these and more innovations in this edition of ABB Review.

Enjoy your reading!

M. Wierod

Morten Wierod
Chief Executive Officer, ABB Group

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THE NEW ABB REVIEW

Starting from edition 01/2025, ABB Review will appear in a redesigned format. Changes include:

- A re-vamped and expanded innovation web hub, featuring additional material such as movie clips and short-format articles.
- More case studies and interviews.
- Two print editions per year (instead of four).
- Online-only, articles published between the print editions.
- Further details to be announced in ABB Review 04/2024.

01

ABOUT ABB REVIEW

In continuous publication since 1914, ABB Review is one of the world's longest running technical journals. The journal prides itself on its accuracy and objectivity, speaking "from engineer to engineer". ABB Review is provided free of charge to those with an interest in ABB's technology and objectives.

OUR CHARTER

The objective of ABB Review is to showcase to ABB's customers the latest research results of ABB's >$1 billion annual R&D investment, innovative solutions and achievements, in an objective, permanent, trustworthy and precise way.

02

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With edition 01/2025, ABB Review will be relaunched in a new format →01. As part of this changeover, we are reviewing our distribution mechanism. Our present mailing lists have grown organically over time and are unfortunately not always consistent in terms of data privacy and consent. We thus request that all subscribers (whether they subscribe to the print edition or the email alert) re-subscribe.

The easiest way to re-subscribe is to scan the QR code below, and follow the instructions. Readers unable to use the QR code can also visit the ABB Review web page abb.com/abbreview, and select “subscribe.”

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If you fail to resubscribe, we must unfortunately assume that you no longer consent to your subscription, and you will be automatically unsubscribed from the end of 2024.

I apologize for the inconvenience of this changeover and thank you for your continued loyalty to ABB Review →02.

Andreas Moglestue
Chief Editor

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—
The ABB Dynafin concept is inspired by the powerful motions of a whale's tail.

Ships account for **2%** of global CO_2 emissions.

ABB Dynafin™ is an alternative to the propeller.

ABB Dynafin offers higher efficiency, and lower noise emissions and turbulence.

THE REVOLUTIONARY ABB DYNAFIN™ MARINE PROPULSOR

Propulsion evolution

ABB's new, cycloidal-type propulsor concept – ABB Dynafin – significantly increases a vessel's efficiency and promises to substantially reduce emissions across the marine industry.

Most international trade relies on waterborne transportation. Despite providing the most cost-effective means of moving the goods involved in this trade, the shipping industry suffers from the drawback that ships typically burn heavy fuels that produce greenhouse gases (GHGs), such as carbon dioxide (CO_2), making the marine sector responsible for around 2 percent of human-made CO_2 emissions globally [1]. Indeed, if shipping were a country, it would be the sixth-largest emitter of GHGs worldwide [2].

To address these emissions, the International Maritime Organization (IMO) has declared the ambition to achieve net-zero emissions from

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international shipping by 2050. Alternative energy sources and advanced propulsion technology are seen as crucial elements of the plan to accomplish this goal.

In May 2023, ABB presented a breakthrough solution that looks set to revolutionize marine propulsion – ABB Dynafin, a cycloidal-type propulsor that meets the urgent demand for higher efficiency and emissions reduction.

ABB Dynafin

The innovative ABB Dynafin generates thrust by means of blades that project outward from the bottom of the ship →01. The blades rotate around their own axis and around the axis of the rotatable wheel upon which they are mounted. In this way, and under the control of a sophisticated control system (see the article "Command and control" on page 174 of this edition), ABB Dynafin can achieve very high hydrodynamic efficiencies and change thrust direction almost instantaneously, giving far better maneuverability than arrangements in which a conventional propeller is rotated about a vertical axis to direct thrust.

The ABB Dynafin concept is essentially a cycloidal propeller with individually controlled blades following a trochoidal path, analogous to that of a whale's tail. (A trochoid is the curve generated by a point on the radius of a circle as the circle rolls on a fixed straight line.) Trochoidal propellers have been studied before, but until now, technology constraints have prevented them from being commercialized and introduced to the market.

Rotational movement of the main wheel is produced by an electric direct-drive motor. The main wheel rotates at a relatively low 40 to 80 rpm and has four to six identical blades →01. The direction of rotation is kept the same under all operational situations and thrust amount and direction are determined by a combination of main wheel rpm and blade adjustment. Initially, ABB is concentrating on developing ABB Dynafin units in the power range of 1 to 4 MW per propulsor →02.

Models and modeling

The development of ABB Dynafin was greatly aided by using computational fluid dynamics (CFD) simulations to evaluate hydrodynamic performance as well as by scale-model open-water testing →03a-b Much of the detailed work was carried out in collaboration between ABB and a team from the VTT Technical Research Centre of Finland in Espoo, Finland (see the article "Bubbling under," on page 168 of this edition.)

The next step in hydrodynamic performance testing was to expose ABB Dynafin to conditions closer to those in the real world by retrofitting propulsors to a platform support vessel's hull. Performance could then be compared against existing Azipod® units in the same power range.

> The blades rotate around their own axis and around the axis of the rotatable wheel upon which they are mounted.

Following the successful simulations and scale-model and vessel-hull tests, ABB engaged in productive discussions with several ship design offices, shipyards and ship owners and operators to validate the feasibility of the concept.

Key efficiency factors

Several factors drive the high efficiency of ABB Dynafin, such as its larger propulsive area, which lowers the propeller loading, giving the lowest thrust loading coefficient. The lower this coefficient, the higher the ideal open-water efficiency of a propulsor. Further, ABB Dynafin's geometry makes it ideal for shallow-water vessels as it protrudes less far than an equivalent screw propeller. In contrast to a traditional vessel, which has a rudder and struts for the shaft that create drag, a cycloidal propulsor only has the

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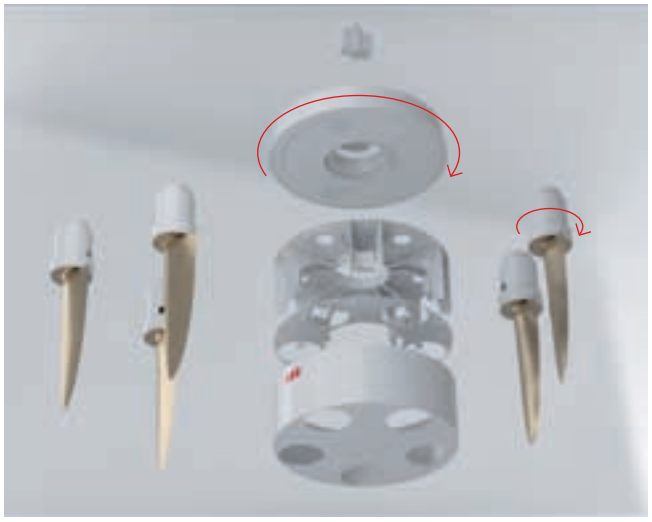

01

02

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01 Each blade can rotate, as can the main wheel onto which they are mounted.

—
02 Two (shown here) or even four sets can be fitted to a vessel, giving up to 16 MW of installed power.

—
03 CFD simulations provided the fastest and most cost-efficient way to investigate hydrodynamic phenomena and to improve the concept.

03a Twin-set simulation. The position, z, depicts wave height around the vessel, with blue values indicating calm water. The static pressure legend applies to the blades.

03b Fluid flow around individual blades.

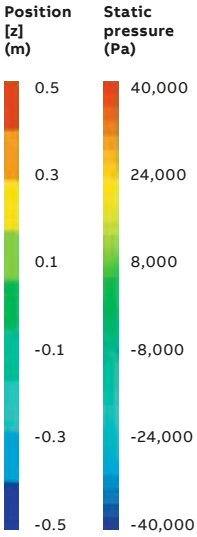
blades protruding from the hull, giving a better hydrodynamic performance.

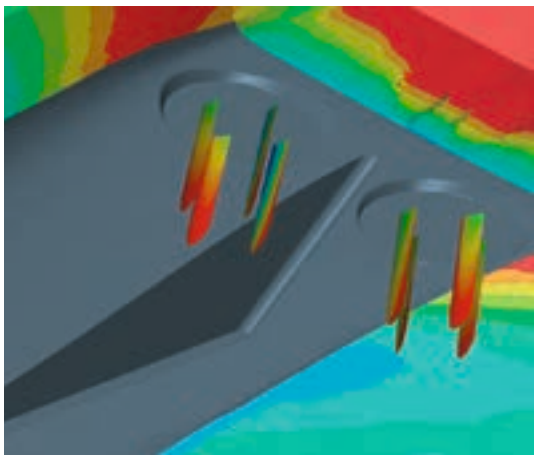
A further factor that drives efficiency is the ability to control each blade individually. Each blade is controlled by an electric motor, a frequency converter (to control torque and rpm) and control logic. This arrangement enables the imitation of a high-efficiency whale-tail movement and adjustment of the blade movement (eccentricity, advance ratio and angle of attack) depending on different vessel operational situations, maximizing efficiency and thrust in both transit and dynamic positioning modes →04.

ABB Dynafin has a major advantage over fixed pitch propellers, which are optimized to a single operational point, in that it can adjust the movement of the blades continuously to meet optimal performance over a wide speed range and different wake fields. The unit's control and software technology allows continuous vessel performance optimization throughout its lifetime, creating the concept of a "digital propeller." ABB Dynafin can also be operated in "rudder mode," meaning that all the blades are controlled as conventional rudders. This feature brings benefits not only for double-enders and sail-assisted vessels but also increases redundancy in failure situations, providing partial steering capability.

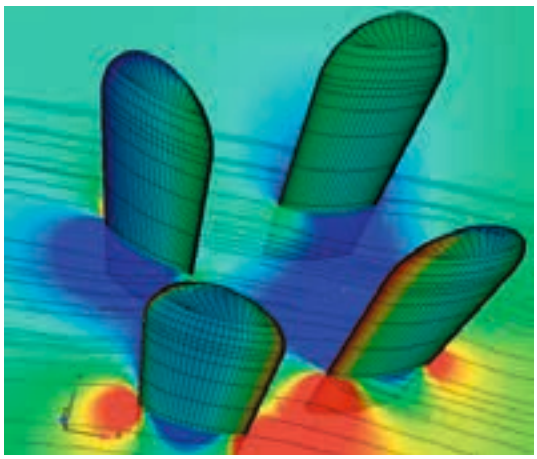
—
Each blade has an electric motor, control logic and a frequency converter to control torque and rpm.

In addition to having a direct electrical power train for both the main wheel and the blade modules, a mechanical bevel gear may be used,





03a



03b

04

— 04 Lake trials demonstrating maneuverability capabilities of a vessel equipped with ABB Dynafin propulsors.

allowing connection to the main engine and extending the benefits to vessel segments where electrical power trains are typically not used.

Other efficiency gains can be made because Dynafin's superior performance allows for smaller power plants (and fuel tanks) to be used. This improvement reduces capital outlay and maintenance costs, enables a more flexible ship layout and frees up room for cargo and passengers. This power-reduction aspect is particularly beneficial to hybrid or fully battery-powered vessels, as the size of costly battery banks can be minimized.

— ABB Dynafin's modular structure and high degree of standardization simplify spare part management.

Dynafin vessels make the least noise
Limits on underwater radiated noise are expected in the near future due to its potential effect on aquatic ecosystems. ABB Dynafin minimizes electromagnetic noise by having the electric motors inside the vessel's hull and minimizes hydrodynamic noise by limiting cavitation and turbulence. In addition, individual blade control enables optimized trajectories to curtail hydrodynamic noise in different operational situations.

High reliability and easy maintenance
ABB Dynafin's modular structure and high degree of standardization simplify spare part management. There are, in any case, fewer components due to the combined propulsor and steering and a direct electrical power train.

The absence of wear-sensitive gears and the main wheel's moderate 40 to 80 rpm minimizes component wear, but when component inspection or replacement is needed, the main wheel is easily accessible from inside the vessel.

A sea of application possibilities
ABB Dynafin delivers a fuel consumption reduction of up to 22 percent compared to a conventional shaftline and a propulsion efficiency of up to 85 percent. Less space is needed for the ship's power plant and fuel tanks. In addition to high efficiency, ABB Dynafin also simplifies maintenance and enables superior vessel maneuverability.

ABB's expertise in hydrodynamics, mechanical systems, ship electrification and automation and control puts the company in a unique position to further improve the ingenious ABB Dynafin. This propulsion system adds a new level of adaptability and intelligence to vessel performance and changes how the shipping industry thinks about propulsion systems. •

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The concept of Dynafin builds on deep understanding of hydrodynamics.

Its development is built on extensive analysis.

Excellent performance was achieved.

CAVITATION ANALYSIS OF ABB DYNAFIN™ TROCHOIDAL PROPELLERS

Bubbling under

Cavitation and hydrodynamic performance are critical aspects of ABB Dynafin™, ABB's high-efficiency ship propulsion system, that have been investigated at the VTT Technical Research Centre of Finland via computational fluid dynamics (CFD) [1]. These methods deliver insights that lead to improved designs.

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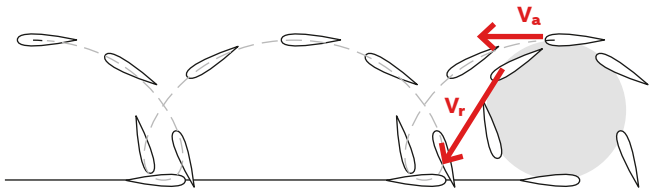

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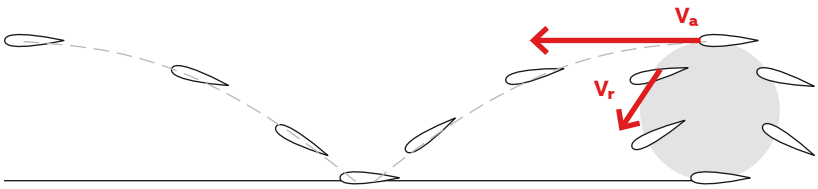

01b

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01 Blade trajectories in propellers, where V_a denotes the advance speed, and V_r the angular speed.

01a Cycloidal low-pitch propeller.

01b Trochoidal high-pitch propeller.

The innovative ABB Dynafin is a marine propulsion system that generates thrust by means of blades that project outward from the bottom of the ship. The blades rotate around their own axis and around the axis of the rotatable wheel upon which they are all mounted. The ABB Dynafin can achieve very high hydrodynamic efficiencies and change thrust direction almost instantaneously, giving far better maneuverability than an azimuthing thruster, where a conventional propeller is rotated about a vertical axis to direct thrust.

The ABB Dynafin concept is essentially a cycloidal propeller with individually controlled blades following a trochoidal path →01. (A trochoid is the curve generated by a point on the radius of a circle as the circle rolls on a fixed straight line.) Trochoidal propellers have been studied before, but until now, technology constraints have prevented them from being commercialized and introduced to the market.

Cavitation
Cavitation describes the formation of small vapor-filled cavities, such as bubbles, in a liquid. Cavitation can occur when local static pressure falls below the liquid's vapor pressure. This undesirable phenomenon often causes noise plus propeller erosion and damage.

Accordingly, to gain a detailed understanding of ABB Dynafin's hydrodynamic and cavitation performance in a ship-scale context, the VTT Technical Research Centre of Finland and ABB collaborated on a numerical study to investigate a full-scale trochoidal propeller in wetted and cavitating conditions. The analyses are based on transient viscous-flow CFD simulations using both open-source OpenFOAM and the commercial STAR-CCM+ software tools. Cavitation modeling is done using volume-of-fluid (VOF)-based homogeneous multiphase mixture flow models with standard Reynolds-averaged Navier–Stokes (RANS) and hybrid RANS large eddy simulation (RANS-LES) turbulence modeling approaches.

—
Cavitation is modeled using a transport equation for the liquid phase volume fraction.

Flow based on Navier-Stokes equations
The homogeneous flow model used is based on the Navier-Stokes equations for two incompressible, isothermal and immiscible fluids with phase change accounted for by mass-transfer models.

Liquid flows around an ABB Dynafin blade are turbulent and this situation has to be taken into account. For this task, the popular **k – ω** shear stress transport (SST) base turbulence model is used [2]. The study also uses a scale-adaptive simulation (SAS), which is a hybrid RANS-LES turbulence modeling method that functions with the SST model [4]. The SAS method has the advantage that it adjusts the turbulent length scale based on local flow.

—
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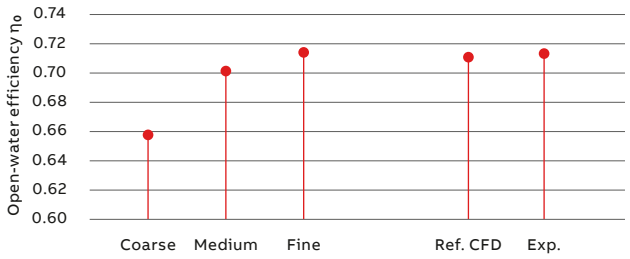

02

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02 Hydrodynamic efficiencies: four predicted with CFD and one showing experimental data.

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03 Illustration of CFD predicted flow field for the four-bladed device.

03a 2-D section.

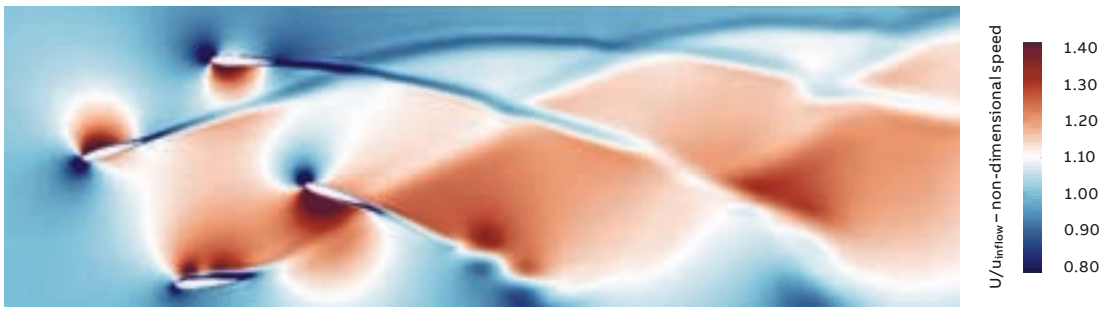
03b Vortices in 3-D.

Mass transfer models
Cavitation is modeled using a mass transport equation for the liquid phase volume fraction. Different mass transfer models can be employed to account for local effects in the flow. Several cavitation mass-transfer models have been developed and typically, the mass-transfer rate is proportional to a pressure difference from saturation pressure. A number of mass-transfer models are available in OpenFOAM and STAR-CCM+ for homogeneous mixture modeling. For the present work, the model described in [5] is used with both solvers.

The flow equations are discretized with a collocated finite volume method. Time-accurate simulations are carried out to resolve the flow field. In the case of OpenFOAM simulations, a first-order implicit scheme is applied for time derivatives, with a time step determined by a maximum Courant number of 1 in the vicinity of the blades. (The Courant number indicates an appropriate size of the time step for a given velocity flow speed range.) In practice, this resulted in physical time steps corresponding to 0.1 to 0.5 ° of the main wheel's rotation. For STAR-CCM+ simulations, a second-order, three-level implicit scheme is applied for time derivatives. The used time step size corresponded to 1 ° of revolution of the main wheel. For both solvers, all flow variables are discretized using second-order spatial schemes with upwind-biased methods applied for convective terms.

—
The numerical methods are tested against two cases for which data and numerical analysis are available.

Validate then test
To ensure the validity of the numerical methods, they are tested against two cases for which experimental data and numerical analysis are available:



03a

03b

σ_{Veff}	Thrust coefficient in x-direction, K_{Tx}	Torque about the z-axis	Open-water efficiency
Trochoidal trajectory			
5.0	4.28	4.45	0.77
3.0	4.27	4.41	0.77
2.0	4.29	4.47	0.77
1.7	4.20	4.74	0.71
1.5	4.13	4.77	0.63
1.0	3.11	5.87	0.42
Optimized trajectory			
5.0	4.26	4.28	0.81
3.0	4.27	4.26	0.80
1.7	4.24	4.25	0.80
1.7*	4.16	4.12	0.81
1.5	4.06	4.23	0.77
1.0	2.87	4.38	0.52

04 *STAR-CCM+ result

— 04 Performance coefficients of the ABB Dynafin device as functions of the cavitation number with different blade trajectories.

- A four-bladed trochoidal propeller. Here, previous open-water and self-propulsion experiments have been carried out at the VTT towing tank and numerical analysis was performed [6].
- A five-bladed cycloidal propeller, for which experimental results are available.

Once it is shown that the methods work in these two cases, the five-bladed ABB Dynafin concept can then be investigated under wetted and cavitating conditions using the same methods. The validation cases were analyzed in model-scale conditions, whereas the five-bladed ABB Dynafin concept was studied in full-scale conditions. The diameter of the ABB Dynafin device is 3 m, the span of the blades is 3.5 m and a symmetrical blade profile is used.

Results of the validation cases

For the simulations, boundary conditions were set, for example:

- The devices were modeled as if inside a rectangular cavitation tunnel.
- Flow speed was specified at the inlet and pressure at the outlet.
- A no-slip condition was used for the tunnel ceiling and a no-slip moving wall boundary condition was used for the blades.
- The sides and bottom of the rectangular domain were modeled as slip walls.

→02 shows simulated hydrodynamic efficiency values for the four-bladed trochoidal device based on three different grid resolutions, together with FLUENT simulations [6] and the model-scale experimental result. The latter two correspond well. The case is pure trochoidal motion with $\boldsymbol{\lambda} = 1.6$. The simulations converge monotonically toward the experimental result and the fine grid result is within 0.2 percent of the reference experimental value. The deviation of the medium grid result is roughly 1.5 percent and the coarse grid result is a bit less than 8 percent.

→03 illustrates the instantaneous flow field from fine grid simulations of the four-bladed device. Accelerated flow near the blades and in the middle of the device, as well as individual blade wakes, are clearly visible. Resolution of wake flow features is sustained in the slipstream. Blade wakes interact with succeeding blades at the aft part of the device, as well as farther downstream.

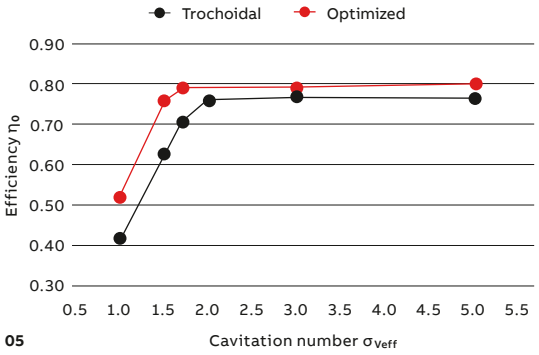
Cavitation performance of the ABB Dynafin

For the cavitation performance of the ABB Dynafin, calculations were performed based on a cavitation number, σ_{Veff}, ranging from 1 to 5 – that is, from wetted or non-cavitating (high cavitation number) to fully cavitating conditions (low cavitation number). Most conditions were analyzed with OpenFOAM and a comparison

— A high open-water efficiency of 0.8 is obtained with the optimized trajectory.

at a selected operating point was carried out with OpenFOAM and STAR-CCM+ solvers. A $\boldsymbol{\lambda}$ of 1.6 was used for all cases. In addition to a pure trochoidal trajectory, an optimized pitch function was also analyzed. Optimization, in this case, was based on further improving the efficiency and cavitation performance of the device.

Results at different cavitation numbers, in terms of the global performance coefficients, are given in →04. The table shows the coefficients for the trochoidal trajectory used and the optimized trajectory. The results shown in the table are also shown in →05 to compare performance coefficients for trochoidal and optimized blade trajectories.



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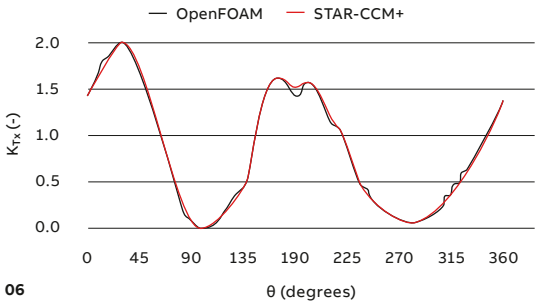

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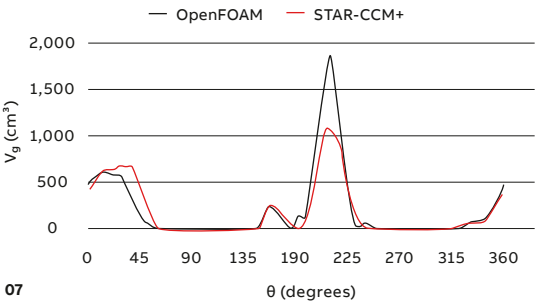


07

— 05 Efficiency of the ABB Dynafin with cavitation numbers. Comparison of trochoidal and optimized blade trajectories.

— 06 Thrust coefficient for one blade during rotation of the device. Comparison of OpenFOAM and STAR-CCM+ results at σ_{veff} = 1.7.

— 07 Vapor volume for one blade during rotation of the device. Comparison of OpenFOAM and STAR-CCM+ results at σ_{veff} = 1.7.

A high open-water efficiency of 0.77 is reached with the trochoidal motion and an even better 0.8 is obtained with the optimized trajectory. The performance and thrust remain high with little variation until below $\sigma_{veff} \approx 1.7$ with the optimized blade trajectory. For pure trochoidal trajectory, a breakdown of thrust occurs slightly earlier, and after that condition, there is a decrease in the efficiency curve. Comparing the results from OpenFOAM and STAR-CCM+ CFD solvers, there are slight differences in the predicted thrust and torque coefficients, the coefficients being smaller in the STAR-CCM+ solution. Deviation in torque coefficients is slightly larger than in the thrust coefficients. These differences may be partly attributed to dissimilar temporal and grid resolutions applied, especially in the boundary layers of the blades. Still, predicted hydrodynamic efficiencies are very close to those of the CFD solvers.

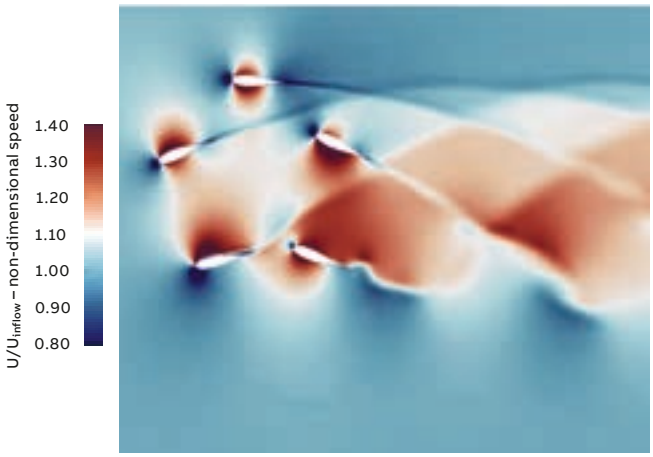
The thrust coefficient for a single blade from OpenFOAM and STAR-CCM+ simulations during one revolution of the main wheel is shown in →06. The evolution of vapor volume for a single blade is shown in →07: As the blades rotate in the fore part of the device (θ 315° to 45°) and go downward, cavitation starts to form first near the root, then grows spanwise to cover a thin region near the blade leading edge. A cavitation-free region is followed by a two-peaked pattern of increasing vapor volume at around θ ≈ 160° and θ ≈ 200°. Greatest vapor formation takes place at the aft part of the device, that is, after the blade has passed θ ≈ 180°. Between roughly 240° and 315°, a cavitation-free region appears. The applied homogeneous-mixture CFD methods predict mainly sheet-type cavities on the blades.

Overall, the thrust and gas volume values have similar forms for each CFD solver for most of the wheel's rotation. Differences arise mainly when the blade passes through the wake generated by the other blades as the main wheel rotates – for example, near **θ** = 180°. →08 shows the scaled, non-dimensional flow speed (U/U_{inflow}) at a middle **z**-plane of the device, illustrating that wakes of individual blades are more distinctly resolved in OpenFOAM simulations and as a blade passes through the wake of another blade, the wake's effects are more pronounced in the blade's force time history. Note that there is a slight deviation in shapes of vapor time evolution close to **θ** ≈ 45° – ie, when the rotating blades meet an undisturbed flow. Possible causes of this discrepancy require further investigation. In addition to differences in grid resolutions, the time step used in the STAR-CCM+ simulations was a bit larger, which may increase numerical diffusion in the flow solution. The shorter time step applied in the OpenFOAM solution can also result in a more resolved vapor field.

— OpenFOAM simulation results compared well with available experimental and reference simulation data.

Simulation matches reality

This VTT and ABB collaborative study shows that the performance of the ABB Dynafin with a purely trochoidal motion of the blades is good,



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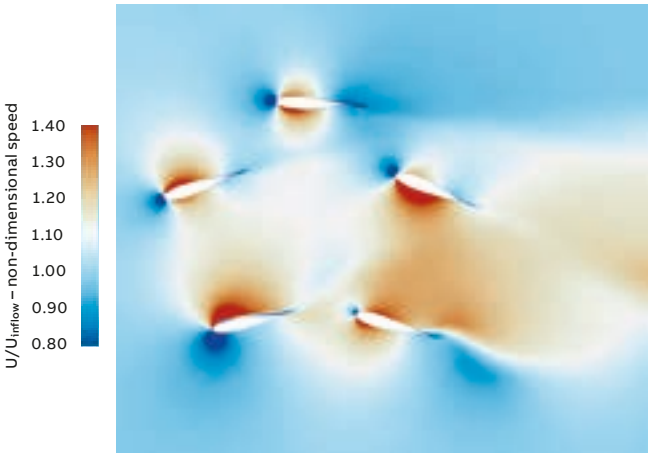

08b

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08 Illustration of CFD predicted flow field at σ_{Veff} = 1.7. The flow speed has been scaled with the inflow speed.

08a From OpenFOAM simulations.

08b STAR-CCM+ simulations.

with efficiencies near 0.8. Under the conditions considered, performance remains excellent up to relatively low cavitation numbers. Cavitation and hydrodynamic performance can be further enhanced with an optimized blade pitch function, which leads to improvement over the pure trochoidal motion.

OpenFOAM simulation results compared well with available experimental and reference simulation data. Overall, the CFD methods applied to the ABB Dynafin device produce similar results. Differences in the flow field and time evolution of the vapor volume were observed and discussed. More operating points should be investigated to obtain more precise data about the onset of cavitation and the trend of the performance coefficients. A detailed description of the study described in this article can be found in [1].

Future work includes a numerical uncertainty assessment with respect to grid resolution. Further, the implementation of scale-resolving turbulence modeling techniques could allow for a more thorough investigation of cavitation dynamics and multiphase flow. Moreover, to supplement current mixture multiphase flow models, the application of two-fluid methods could ensure cavitation features and types are represented more completely. •

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Acknowledgements

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PRECISE CONTROL OF ABB DYNAFIN™ TROCHOIDAL PROPELLERS

Command and control

In contrast to a traditional ship's propeller, ABB's revolutionary marine propulsor, the ABB Dynafin, has multiple moving parts. To obtain optimal performance, these parts must be precisely orchestrated – even under the toughest oceanic conditions. For this task, a sophisticated control system is required.

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ABB Dynafin is a revolutionary marine propulsion system designed to extend the abilities of cycloidal-type propulsor concepts by introducing individual blade control with permanent magnet motors. The concept combines propulsion and steering, with blade trajectories inspired by the movement of a whale's tail. Due to its effective pitch angle change of each blade, ABB Dynafin delivers much better hydrodynamic efficiency and maneuverability than traditional screw propellers.

Each blade is driven by an individual blade motor, allowing the setting of the exact pitch angle.

It is essential that ABB Dynafin's propulsion and steering elements are very carefully controlled so they follow exactly the required trajectories, even in very dynamic environments. For this, a precise control strategy is required.

Control via a "digital propeller design"

ABB Dynafin has two major parts: a main propulsion motor and a rotating lower part with blade motors →01. The main motor, which is fixed to the vessel hull, rotates the lower part and thus delivers the main thrust. Each blade on the lower part is driven by an individual blade motor, allowing the setting of the exact pitch angle required for adjusting the thrust magnitude and direction. The blade drives are powered through a slip ring unit, enabling the free rotation of the main propulsion motor. The slip ring also provides the physical link needed to communicate with the blade drive control units.

The principal control commands in a typical vessel are the rudder angle and propeller speed. In ABB Dynafin control, the captain can give the desired thrust magnitude and direction from the bridge's remote control via common control interfaces (ABB Dynafin replicates the ABB Azipod® experience in terms of compatibility

Dynafin has numerous moving parts, whose actions must be coordinated and optimized.

ABB developed a control algorithm.

High standards of performance, safety and redundancy are fulfilled.

with existing systems and extending and improving user experiences). This ability to effect a "digital propeller design" broadens the availability of standard modes of ship operation. For example, in addition to the standard modes – such as bollard pull, dynamic positioning, sea

Behind this simple-sounding steering approach lies a sophisticated control system.

transit and maneuvering modes – new modes and trajectories can be created and supplied since each blade can be controlled individually. Each mode is implemented by optimizing the

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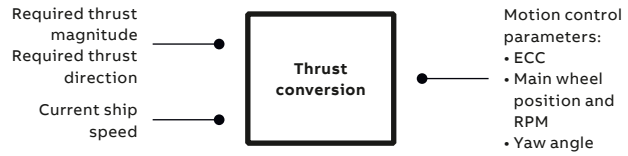

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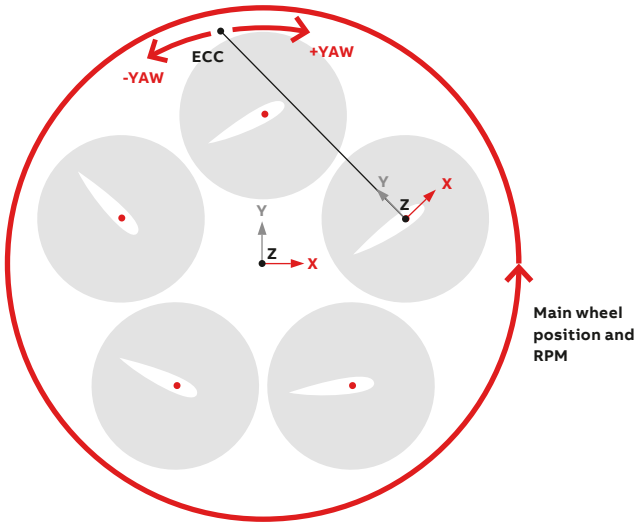

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01 Thrust conversion: required thrust magnitude and direction is converted to motion control parameters.

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02 Motion control parameters: ECC, yaw angle, and mainwheel position and RPM.

control parameters for that mode, resulting in different blade pitch angle trajectories and main wheel behavior.

Behind this simple-sounding steering approach lies a sophisticated control system.

The ABB Dynafin control system

On a high level, the ABB Dynafin control system translates the speed and heading that the captain requests into an appropriate main wheel speed and a pitch angle for each blade. This part of the control – the thrust conversion module – takes place in the main control unit. The thrust conversion module then supplies the speed reference to the main propulsion drive and provides each blade drive control unit with the motion control parameters needed to achieve the required blade trajectory.

The low-level motion control on each blade control unit is designed to implement the trajectories defined by the motion control parameters designated by the thrust conversion. Motion control parameters define trajectories that each blade will follow during one rotation of the main wheel. These parameters are the eccentricity point (ECC), ie, the point to which all blades are perpendicular; the main wheel position and rotation speed; and the yaw angle. Yaw defines the rotation of the thrust vector effected by rotating the eccentricity point →01-02. The eccentricity parameter is used to calculate the pitch angle

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Motion control parameters define trajectories that each blade will follow during one rotation of the main wheel.

of the blades. To create a whale tail motion, the blades follow a trochoidal path where the eccentricity point is outside of the circumference of the rolling circle. In the case of ECC = 0, the blades will be rotating along the circumference with a pitch angle following the circle.

The main wheel speed reference from the thrust conversion is sent to the main propulsion drive. The actual speed and position of the main wheel are then measured by the main wheel encoder and sent to the main control unit. Tests have proven that the ABB Dynafin control algorithm achieves blade-tracking with the required precision.

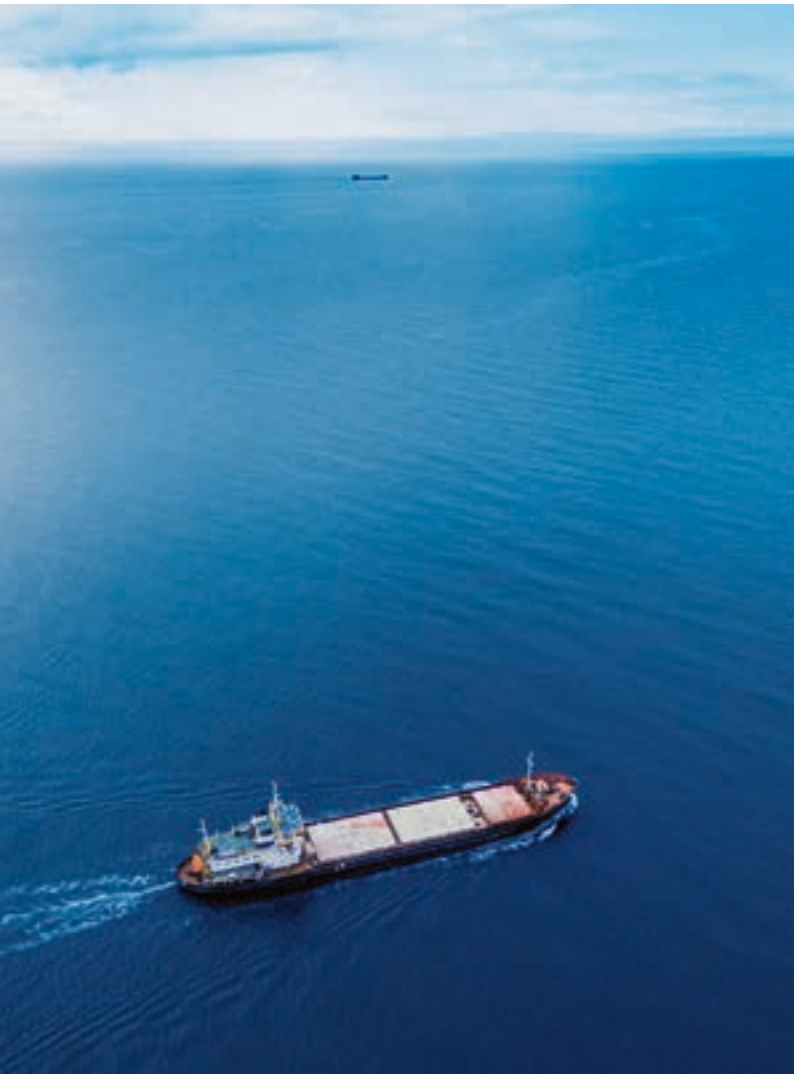
The main wheel encoder measurements are also sent to the blade control units in each blade module so they can precisely maintain their position during the main wheel's rotation. As mentioned, blade motion control is implemented in the blade control units separately for each blade drive. This separation allows fast communication with each drive and reduces the computational load on the main control unit. The low-level control executes in sub-millisecond cycle times. The blade position and angular speed are measured by encoders on the blades and sent directly to the blade control units. It is important to note that the number of blades has no effect on the overall control system and the control can be implemented in a modular way for a higher or lower number of blades.

Driving force challenges

The low-level control is based on the blade pitch function in the form of a mathematical model and on knowledge of disturbances (hydrodynamic loads, frictional loads, acceleration changes, etc.) To achieve high performance, the ABB Dynafin propulsion system must follow the predefined blade pitch function with high accuracy. However, several challenges arise when attempting to control blade motion:

- The blade's pivot point is typically not aligned with its principal axis of inertia. This misalignment induces a centrifugal torque during wheel rotation, complicating blade control.
- Many blade pitch functions aimed at achieving high efficiency require both high acceleration and rapid acceleration changes for blade motion, which pose difficulties for the blade motors and drives to handle effectively.
- Certain blade pitch functions involve changes in blade rotational direction, necessitating blade motors to compensate for frictional torque.
- Hydrodynamic loads applied to the blades introduce tracking errors in blade pitch functions. Failure to accurately follow specified blade pitch functions can degrade propeller performance, increase torque on wheel motors and reduce overall efficiency.

The ABB Dynafin control algorithms are designed to cope with these challenges.



The torque reference from the blade control is generated for each blade drive using a feed-forward loop →03. Motion control parameters (RPM, ECC, yaw and main wheel position) are input to the blade motion control block, where a position reference is calculated as well as the necessary feed-forward model outputs for disturbance compensation. The cascaded blade-drive control block calculates the final torque required for high-precision tracking of the blade motion. Employing this model-based torque feed-forward compensation provides an accurate torque value to compensate for centrifugal torque, acceleration torque, friction torque and hydrodynamic torque, all of which are difficult for the feedback control. Finally, control software handles the limits and transition of trajectories in the final stage for smooth transitions and affordable torque profiles.

HIL testing involves connecting the physical components to a simulation that mimics load and operating scenarios.

Testing with hardware

The ABB Dynafin team has developed a hardware-in-the-loop (HIL) test platform to verify control performance, requirements analysis, failure modes and effects analysis (FMEA), and hardware suitability for the final product →04.

In HIL testing, the system under test is connected to a simulation or model of its environment. The system's response to various inputs is then measured and compared to expected results. HIL simulation allows control system evaluation in a controlled environment before deployment in the actual marine environment.

In the case of ABB Dynafin, HIL testing involves connecting all the physical components from the control network topology – such as the main control unit, blade control units, interface cards and I/O modules – to a simulation that mimics the load conditions and various operating scenarios. The motor suppliers provide motor model parameters. Hydrodynamic loads are generated using computational fluid dynamics (CFD) simulations corresponding to the trajectories under test. The power stage of the drives is also modeled.

Initially, a two-blade system was created to verify various aspects of the drives, control units,

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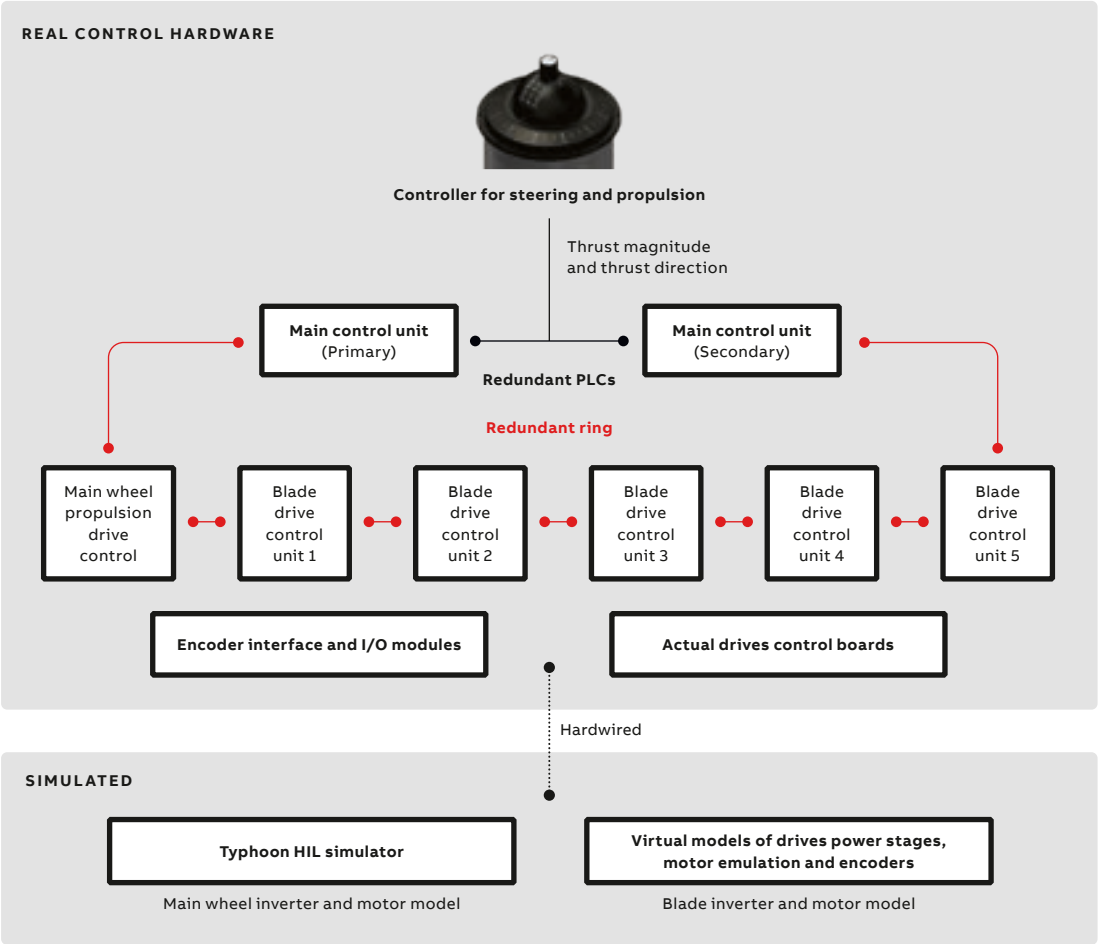
03 HIL setup. HIL testing connects actual product hardware to simulated load and operating conditions.



03

redundancy schemes, blade tracking, etc. Since the control network topology is now frozen, the HIL test system will be expanded to a five-blade setup for the second stage of the testing.

Redundancy and failsafe

At sea, vessel reliability and the safety of the crew are of paramount importance. For this reason, the control network topology has been designed to follow standard requirements, ensuring redundancy and high performance. An extensive design FMEA has been carried out for each design component and, according to “single failure criteria,” active components have been duplicated for redundancy. The FMEA outcome shows ABB Dynafin fulfills the rules established by the International Maritime Organization (IMO) and the International Convention for the Safety of Life at Sea (the SOLAS Convention). For example, in the case of a failure, vessel steering is ensured by switching the failed unit to rudder mode, where the main wheel is stopped and all active blades are used as rudders for steering.

ABB’s Dynafin provides all-round best-in-class performance, efficiency, safety and reliability – all enabled by a sophisticated control system that overcomes the many challenges faced by a marine propulsor composed of multiple moving parts that is exposed to the harsh conditions found at sea. The modular nature of the control system simplifies the extension of ABB Dynafin to cover many more marine applications. •

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COLLABORATION WITH VTT WAS CRUCIAL FOR THE ABB DYNAFIN™ PROJECT

Strength through collaboration

A critical phase of the ABB Dynafin™ project was carried out in collaboration with VTT, the largest research and technology company conducting applied research in Finland. This work is one part of a valuable and ongoing cooperation between ABB and VTT.

ABB collaborated with the maritime team of VTT.

Collaboration included CFD analysis and model tests.

Previous VTT collaboration projects include ABB's highly successful Azipod.

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01 Scale-model testing by VTT at the Otaniemi (Finland) towing tank.

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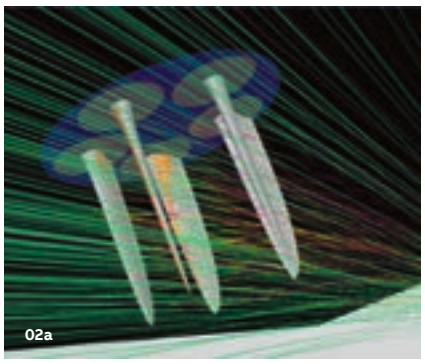
02 VTT performed towing tank tests for comprehensive scale-model testing.

02a "Clean" flowlines.

02b With wake/ cavitation.



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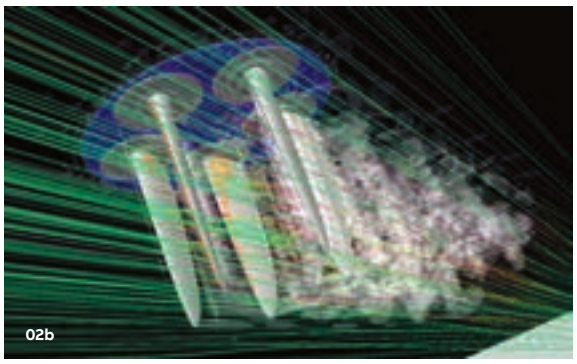

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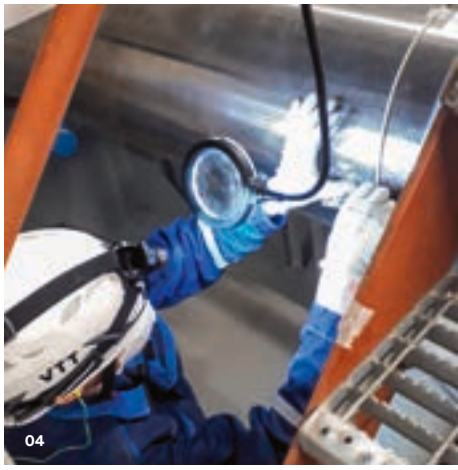

04

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03 The VTT towing tank is large enough for comprehensive scale-model testing.

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04 VTT possesses all the skills in-house for the complete engineering of test environments. Here, a VTT engineer is installing instrumentation to a ship propeller shaft in preparation for sea trials.

VTT is a visionary research, development and innovation partner and one of the leading research organizations in Europe. VTT's over 2,000 professionals work to develop systemic and technological solutions that can bring about fundamental transformation.

The VTT maritime team is focused on propulsion hydrodynamics, ship energy efficiency and structural problems on ships. For hydrodynamics, VTT has strong computational fluid dynamics (CFD) capabilities coupled with codes developed in-house for quick assessment of hydrodynamic problems. Numerical assessments are backed with strong expertise in model-scale and full-scale measurements.

VTT's collaboration with ABB has deep roots, going all the way back to the development of the first Azipod® propulsion units in the 1980s. This early work included hydrodynamic assessment of Azipod propulsion units with computational tools and with model tests. Another major topic for cooperation was the assessment and measurements of ice loads on Azipod propulsors. Measurements from the harshest ice conditions helped ABB to develop Azipod propulsors for the highest ice classes. Material and component testing for some of the Azipod parts has also been carried out at VTT testing facilities.

Cooperation on the Dynafin product started in 2014 when ABB approached the VTT maritime team to assess new propulsor concepts. These concepts included paddle wheels, flapping foils and cycloidal propellers. Lacking prior systematic studies of these concepts, it was essential to simulate them with a wide range of parameters to understand the hydrodynamic potential of each one. In this task, the tools developed in-house by VTT were important as they enabled a quick assessment of the hydrodynamic performance of each concept. Later, more accurate but time-consuming CFD analyses were carried out for the chosen ideas. The chosen cycloidal approach with trochoidal blade motion would be the starting point of the Dynafin product development. When the concept was selected, the numerical simulations were verified with model tests by VTT at the Otaniemi (Finland) towing tank →01-03. The VTT maritime team helped ABB design the model device for the tests and between 2017 and 2019, several model test campaigns were carried out, including open-water and self-propulsion tests →04.

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VTT's collaboration with ABB has deep roots, going back to the development of the first Azipod propulsion units.

Recently, the research around novel marine propulsors at VTT has continued in a research project called UltraPropulsor, where several companies, including ABB, are developing related products and concepts. VTT is coordinating the project and carrying out a public research project that aims to deepen understanding of cavitation modelling, hydrodynamic modelling, ice loads and propeller materials. •

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THE VISION, TALENT AND TENACITY BEHIND ABB DYNAFIN™

People power

Some of the multidisciplinary team responsible for ABB Dynafin pose beside the lake where testing took place.

A conversation with Veli-Pekka Peljo, who led the multidisciplinary team that created ABB Dynafin™.

Veli-Pekka Peljo, Senior Project Manager, Solutions Development →01, joined ABB Marine & Ports in 2003 as a design engineer and immediately rolled up his sleeves on the continued development of ABB's Azipod® propulsion technology. Ten years later, he was called on to helm the multidisciplinary team that gave birth to ABB Dynafin, launched in May 2023. Here, he explains how the concept came into being, the collaborative effort needed to bring it to the prototype stage and why a clear goal and open mindset are key to handling uncertainty.

It has been a long journey since 2013, when Peljo took charge of ABB's Total New Propulsion project to develop a propulsion unit with an efficiency of over 80 percent. "Already then, electrification of vessels was seen as a trend, but the green transition was still to come. At that time, marine fuel prices were at an all-time high, so fuel efficiency and reducing emissions were at the front of people's minds and became the main drivers for the project."

Right back to basics

When they started out, Peljo and his team understood that it was not possible to dramatically improve the efficiency of conventional screw-propeller-based solutions beyond the incremental improvements already achieved. "To address the challenge, we knew we'd have to go right back to basics – drill down into the theoretical underpinnings of how to create thrust and come up with something radical from scratch."

> Fuel efficiency and reducing emissions were at the front of people's minds and became main drivers for the project.

01

This article looks at the Dynafin story from a personal angle.

Dynafin builds on more than **10 years** of ground-breaking research.

Meeting demands for fuel efficiency, Dynafin could not be timelier.

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01 Veli-Pekka Peljo is passionate about ABB's work in advanced marine propulsion concepts.

ABB first enlisted the help of engineering students at Aalto University in Espoo to do a big-picture analysis of the ideal propulsor in what they call a Product Development Project (PDP) [1]. They studied the literature to identify what concepts had been floated in the past and what patents were available. "That generated a lot of ideas – everything from screw propellers, paddle wheels and air propulsion to electromagnetic thrusters and biomimetic propulsion – the Aalto guys analyzed how fish, different sea mammals and even insects create thrust," Peljo says.

The combined Aalto/ABB team ended up with 69 concepts, all of which were tested against ideal propulsion theory. Two major criteria for the best solutions were optimal utilization of the transverse area at the back of a vessel and enabling the greatest efficiency at the lowest cost. "That involved a lot of workshops where we finally identified five concepts to take forward: Azipod® XL, a rim-driven nozzle propeller, an advanced paddle wheel concept, a flapping hydrofoil and a trochoidal propeller," explains Peljo.

"After further iterations, we saw that using a flapping foil or blade that mimics the movement of a whale's tail (known as a trochoidal trajectory) was undoubtedly the most efficient solution. That was the germ of the idea that became the ABB Dynafin."

Solving the puzzle

The challenge was how to connect the flapping foil to the rotational movement of an electric or diesel motor shaft to propel a vessel. "You could have a single foil moving up and down, but we figured the best way would be to use multiple vertical blades connected to one central rotating wheel. We then contacted VTT – a state-owned technical research center in Finland and one of the top institutes in Europe – to collaborate with us in creating hydroanalytical models to see exactly how this set-up would generate thrust [2].

"The solution was to give each blade its own driving motor, allowing for independent control so you can pre-program the angle of attack of each blade against the inflow as the main wheel rotates, taking into account the vessel's wake field."

"VTT were very fast to prove the concept, with their calculations indicating an efficiency of over 0.8 with an optimized trochoidal trajectory of the blades. We also used their formulas to optimize geometry factors, including the span and chord dimensions of the blades, and operational parameters such as RPM."

CFD proves the concept

The next step was to create an initial design for computational fluid dynamics (CFD) analysis, which – as the combined project team expected – validated VTT's formulas and showed that the solution works. "Doing CFD, especially 3-D CFD, is time-consuming as a single model can take up to a day to process. You need to have come quite a long way before you do it. We were then able to extract the load data for detailed dimensioning of the supportive structure – for example, the center wheel, blade motors and bearings," says Peljo.

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We saw that using a flapping blade that mimics a whale's tail was undoubtedly the most efficient solution.

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Roderick Craig
External contributor

02

It was only after doing the CFD that the team started to really think about how they could make the concept work in real life. Having little experience in control software solutions, Peljo and his colleagues Mirva Nevalainen, Product Manager, and Jukka Varis, Technology Manager, pitched the concept to Bin Liu, Senior Principal Scientist and his team at the ABB Corporate Research Center (CRC) in Västerås, Sweden and asked if they could make a model-scale prototype. "Pre-programming the movement and angle of attack of the blades was one of the biggest challenges, but being world leaders in robotics – they are the experts behind ABB's family of YuMi® collaborative robots – this was well within their capability."

Starting in 2016, the ABB teams collaborated on a novel cycloidal propulsion technology project, resulting in a prototype and the first novel small-scale demonstrator vessel, which was built and operated on Lake Mälaren, just outside of Västerås.

Defining moment

The resulting prototype was hydrodynamically tested in the VTT model basin in Espoo, Finland and then self-propulsion and maneuvering capabilities were confirmed in open-water lake trials in Sweden. It worked as predicted. "We did everything you'd do in a full-scale sea trial program. That was a fantastic milestone and confirmed all our hard work. We knew then we could really make the concept, which we originally called 'Foilwheel,' fly as a world-first digital propeller with extraordinary efficiency," comments Peljo.

To those who might wonder why nobody had done this sooner, Peljo's answer is: it's not that simple. "ABB Dynafin may look similar to some mechanical solutions, but inside it's totally different – the main thing being the blade motors and entire drive train. Instead of mechanical levers controlled by hydraulic servo actuators, we have electric motors with low RPM and high torque that we can match with the propeller blades at full scale."

He says the final ABB Dynafin units will be of standard design, although of different propeller diameter sizes depending on the power factor. This shortens delivery lead time. "Then you just select the right blade length to fit the vessel draft. It could be that we offer only two different blade lengths, but our target is to keep the blades above the baseline."

The fatigue strength of the blades is a critical design issue, so they need very careful design to ensure the required service life with high reliability. "We're currently thinking martensitic casted stainless steel but given certain manufacturing constraints, we may need to use composites for the longer blades on higher-power units. We're also working on details like sealing solutions to achieve an optimal total cost of ownership."

Target markets

In terms of which vessels the concept is most suited to, Peljo explains that right now they are "just scratching the surface." He elaborates, "we are aligning it with customer requirements for different segments, but there are a lot of possibilities. Transit vessels will see the biggest benefit and the faster the speed, the bigger the benefit. But we're mostly looking at 12 to 20 knots at this stage. With ABB Dynafin, you get many different design points in just one propeller: one for maximum sea-trial speed, one optimized for economy speed, one for safe return to port at six knots, one for dynamic positioning operation and so on. It's very versatile and can suit all sorts of ship types."

ABB Dynafin can change thrust direction through 180 degrees in seconds – ideal for dynamic positioning.

In terms of power factors, ABB is working towards four sizes, from 1 MW to 4 MW. Four 4 MW units on a vessel would give propulsion power of 16 MW. "There's interest in the market to go even higher, so we're also looking at 5 MW units and upwards," adds Peljo.

Photo fig. 02: Used with kind permission from Neoline. (©NEOLINE/MAURIC)

02 ABB Dynafin can operate in rudder-only mode for sail-powered vessels or when hybrid vessels switch to sail-assisted mode.

Thanks to its integrated controllable pitch propeller (CPP) feature, ABB Dynafin has the dynamic positioning capability necessary for offshore vessels. “It can change thrust direction through 180 degrees in seconds, providing a very fast response time if you need to change vessel heading. With multiple units, we’re also looking at how ABB Ability™ Marine Pilot Control can best utilize ABB Dynafin unit’s capabilities for all operational modes and autopilot configurations, with a view to remote operations and eventually autonomous operations.”

> Crucial for success were the great partners in Aalto University, VTT and the ABB Corporate Research Center.

There are also low-vibration vessel cases. “The RPM is quite low at full power, but the amplitude is higher. The pressure pulses from a vertical propeller don’t interfere too much with the hull, but we can tweak the blade trajectories even more to eliminate vibration and noise almost completely for silent operations.”

Moreover, ABB Dynafin boasts other valuable features, such as regenerating power when braking the vessel, just like a self-charging hybrid car. “You can charge onboard batteries simply by the action of the water turning the blades like a windmill. Then we also have the so-called rudder mode, meaning that, when the propulsion drive is inactive, that is, with the main wheel stopped, all the blades can work together to steer, for example, a sail-assisted vessel →02.”

Dealing with uncertainty

Peljo highlights that there is always uncertainty when developing a new concept from scratch. “To handle that, the human factor has to be constant; it’s essential to maintain a creative, open mindset and a strong focus on the goal even if the requirements are vague. Innovation is not all about luck and in-the-moment inspiration; we had a lot of arduous concept rounds. Looking back, we could, of course, have moved faster, but we’ve had a lot of parallel projects to work on, too,” he adds.

Having a proven R&D methodology is also crucial. “We use the applied ship design spiral, where you move from mission requirements to high-level concept analysis on the outer circle and gradually work inwards, honing the design in greater detail. You can’t get bogged down in details too soon. Having a clear business case also stops you from getting distracted in theoretical niceties that waste time.”

Kudos for partners

Peljo stresses that there was “no way we could’ve done this alone.” ABB Dynafin has been the result of pulling together expertise in mathematics, hydrodynamics, mechanics, electrical and control, and we’ve had great partners in Aalto University, VTT and the ABB CRC. So, having the right mix of people, combined with ABB’s strong culture of innovation and determination to always do better, has been crucial for success.”

As to his personal motivation, Peljo trained as a mechanical engineer and loves R&D work because no one day is the same as another. “I’d be bored stiff doing the same thing day in, day out. The project was a once-in-a-lifetime opportunity and it’s fantastic to have come so far in bringing ABB Dynafin to reality.”

“Given the high cost of new green fuels and the increase in fully electric vessels, the business case is even more attractive,” Peljo adds. “Contributing to the green shift gives extra meaning and I believe it’s great timing for what is an exceptional novel technology. We are working hard on the details and I can’t wait to see the first ABB Dynafin live on a real ship.” •

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A COMPARISON OF TECHNOLOGIES FOR DECARBONIZING MINING

Electrifying haulage

The mining sector is responsible for up to seven percent of global greenhouse gas emissions [1]. In view of this, ABB is applying its eMine™ framework of methods and solutions to resolving the many questions surrounding the decarbonization of mining transport and associated electrical infrastructures, including vehicles, material loading and unloading points, charging stations, battery chargers, and batteries.

Diesel-powered transportation systems within mines are a major contributor to the industry's carbon emissions.

Electrification reduces ventilation requirements and improves working conditions.

This article discusses different approaches to electrification.

One of the primary contributors to carbon emissions within mining operations is the haulage of materials, a process heavily reliant on diesel-fueled transportation systems. Not only do these systems account for a substantial part of the mining industry's CO_2 emissions [2] but they also increase ventilation requirements for underground mines, which can amount to as much as 70 percent of total operational costs [3]. Therefore, alternative solutions such as trolley assist systems, battery-operated electric trucks, electric conveyors, and electric hoisting systems offer significant promise in facilitating the overall transition to carbon neutrality.

Considering the vast scope of this transformation, simulation has emerged as an indispensable tool in understanding the benefits and addressing the challenges arising from the introduction of such alternative technologies. Against this background, ABB has applied its simulation tools to investigate questions around the decarbonization of material haulage with trucks, and its impact on the associated electrical infrastructure. In view of this, ABB uses simulation tools built on a discrete event simulation (DES) framework. These tools focus on modeling relevant changes in the internal states and outputs of haulage equipment and associated electrical infrastructures such as stationary (eg eMine™ FastCharge) and dynamic energy transfer systems (eg, eMine Trolley Systems) →01. They recalculate and log parameters whenever triggered by events such as interactions between the multiple systems considered in a simulated scenario. In a mining environment, a brief list of the assets involved includes vehicles, material loading and unloading points, charging stations, battery chargers, and batteries.

The application offers a comprehensive set of features designed to tackle the complexities of real-life mine sites. Its graphical user interface eases the modeling and comparison of various truck and conveyor-based hauling methods. Trucks are modeled based on their underlying propulsion technology, ranging from traditional diesel to diesel-electric and battery-electric vehicles and are matched with the required electrical infrastructure for stationary charging or dynamic power transfer systems. The functionality to import Drawing Interchange Format (DXF) files, a format designed for sharing data universally across computer aided design (CAD) applications, allows for the direct translation of

A built-in scenario planning feature makes it possible to explore different hauling scenario variations within the same mine.

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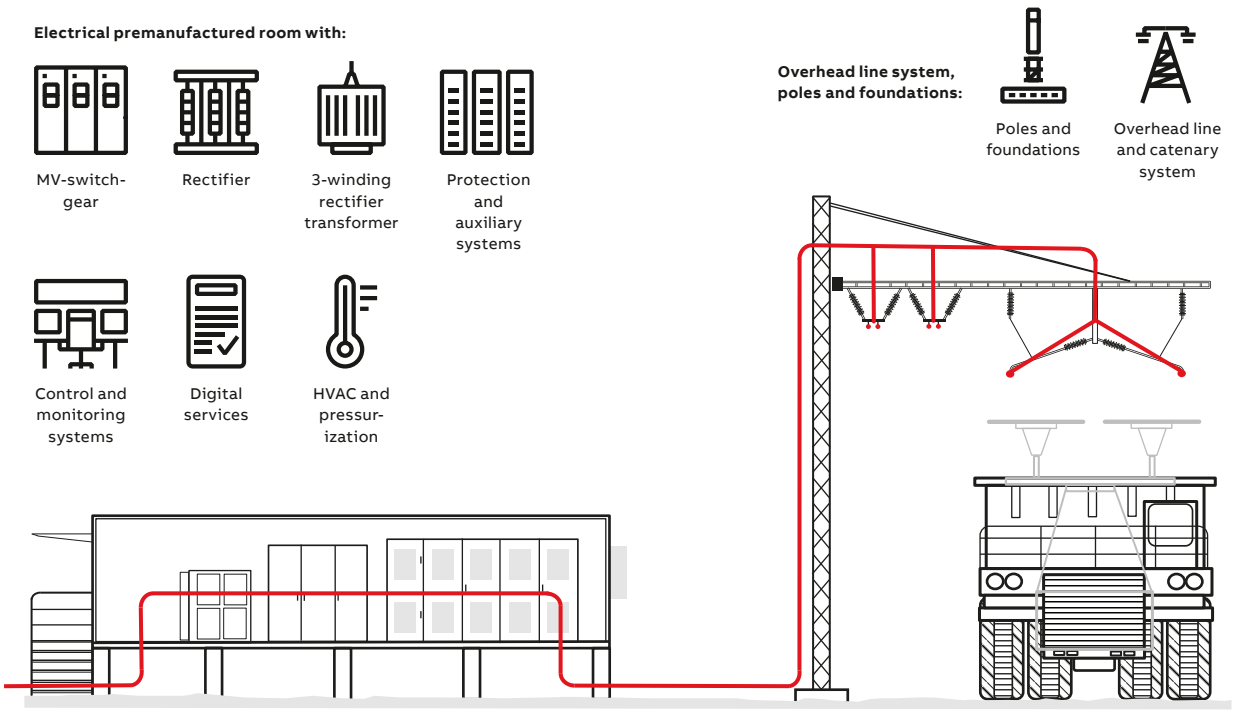


E-MINE™ TROLLEY SYSTEM

The ABB eMine Trolley System comprises a substation and catenary OHL (overhead line). The sub-station connects to the mine power distribution network (medium voltage), converts AC to DC power, and delivers it via the OHL to the truck(s).

Compared to diesel-powered trucks, a trolley system can avoid up to 90 percent of CO_2 emissions for the electrified trucks running on the system and achieve higher productivity, enabling up 2x the truck's speed on the trolley line.

—
Find out how ABB's trolley system is supporting the transition to all-electric mines.

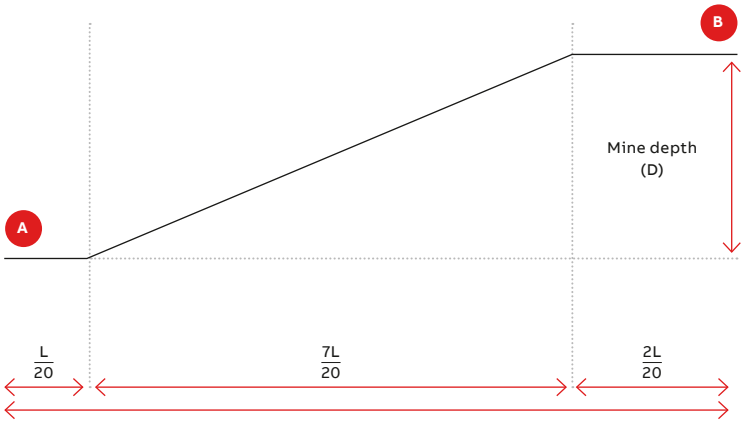
—
01 ABB's eMine™ Trolley System dramatically reduces diesel consumption and emissions.

—
02 Characteristics of the path considered for simulation results.

—
03 Energy consumption in kWh per cycle as a function of haulage path length and elevation gain.

entire existing mine layouts into the nodes and edges forming the directional graphs that model its road network. A built-in scenario planning feature makes it possible to explore different hauling scenario variations within the same mine. Scenarios can be split into multiple time frames, allowing users to consider different road networks, graphs, electric infrastructures, hauling trucks and productivity parameters during the distinct stages of the life of a mine.

Energy consumption per haulage cycle
Load-and-haul operations in mines are characterized by the cyclic paths of vehicles. Such haul cycles will typically change over the lifetime of a mine. Here, the study estimates energy consumption over a haul cycle based on the distance and altitude difference from source to destination. Energy values are calculated for a 290 t payload truck.



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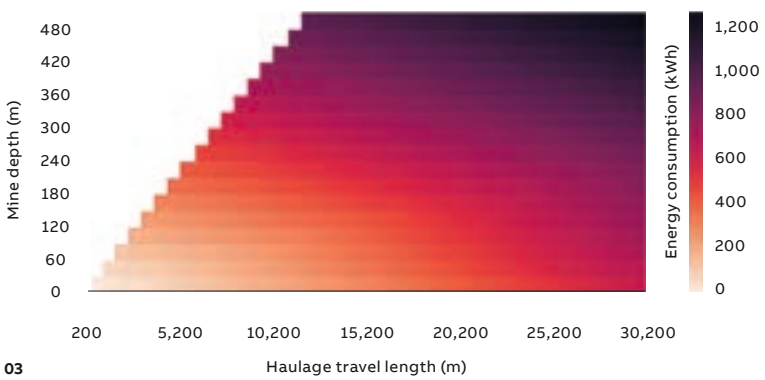

03

The energy consumed during a haul cycle is important. For electrified trucks without a combustion engine, this is the energy that must be supplied by an electrical infrastructure to ensure their operation. Compared to a diesel tank, which stores sufficient energy for a full shift, batteries can supply only a few haul cycles at most.

Disruptive changes in battery cell technology, leading to a significant increase in energy and/or power density, are considered by the authors to be unlikely in the foreseeable future. In consequence, the results presented here will remain valid for the first generation of haul trucks equipped with batteries. The types of paths considered for the simulation are shown in →02. Trucks start at location B, travel to location A, where they are loaded, then return to B to be unloaded. The total travel distance and the elevation gain in the described cycle are denoted L and D respectively.

The values in →03 correspond to the energy needed for a truck to travel along a track, for different lengths and depths (L, D) of track. The study notes that for a fixed length L, the maximal considered D is set such that the slope in the middle segment of the haulage profile does not exceed 12 percent, signifying that segments over which the slope would exceed this maximum are omitted within the analysis of the illustration. Typically, haulage road slopes in open pit mines do not exceed 10 percent.

Three haul cycle scenarios
Every mine is unique – thus, for an exact analysis of the energy consumption within a given mine, one should conduct simulations tailored to the mine's own geography and characteristics. Nevertheless, the objective of this discussion is to offer overarching insights that can be universally applied to various sites based on representative simulations. The three distinct combinations of lengths and depths chosen to approximate the haulage within generic types of mines are summarized in →04.

—
For an exact analysis of the energy consumption, simulations tailored to the mine's specific geography are needed.

Four propulsion systems

1. Diesel

Although diesel is still the main propulsion technology in the mining industry, the transition to electric propulsion systems is well underway. In this context, the diesel fuel required to travel L/2 unloaded to the material source and L/2 loaded back to material destination in the three scenarios is simulated in →05 as a reference point for comparing the CO_2 emissions to be reduced in today's mining operations, where a conversion factor of 2.66 kg CO_2/liter is considered.

2. Diesel-assist trolley

One of the dynamic energy transfer methods used today for haulage trucks is equipping a diesel-electric haul truck with a pantograph. This requires a trolley line and feeding substation system, preferably on selected inclined segments of the haul route. When connected, the drivetrain draws energy directly from the electrical infrastructure to propel the vehicle, enabling the combustion engine to shift into idling mode, reducing diesel consumption.

An overview of the diesel consumption and CO_2 emissions for the representative cycles simulated with ABB eMine™ Simulation Tools is provided in →06. For the simulation, the assumption is that a trolley line has been installed over the entire upward ramp of the trajectory (0.35 L).

Furthermore, trolley-powered propulsion enables a significant reduction in cycle time as summarized in →07.

In →08 the relationship between diesel consumption (in liters) and the proportion of trolley-equipped ramp is shown. The graph considers the three distinct simulated scenarios, each corresponding to different mine depths and track lengths, highlighting potential reductions in fuel as the proportion of the trolley-supplied power increases.

3. Battery trolley with in-motion charging

The following section focuses on battery-trolley propulsion technology, an innovative approach involving in-motion charging. Here, the energy supplied by a trolley line is used for propelling a vehicle and simultaneously charging its battery,

> Battery-trolley propulsion technology is an innovative technique used for propelling a vehicle while charging its battery.

thus taking the place of a diesel engine. It is noteworthy, however, that this technology is not yet fully established but is experiencing rapid evolution thanks to active research, development, and pilot projects [4].

To analyze the potential benefits of this technology on battery utilization, →09 shows battery energy based on maximum charging power, as well as on the proportion of trolley-equipped ramp, with each curve accounting for a different

—
04 Representative scenarios simulated with the simulation tools application*.

—
05 Diesel fuel required to travel unloaded to material source and loaded back to material destination, in the three scenarios.

—
06 Reduction in diesel consumption and CO_2 emissions resulting from integration with electric power.

—
07 Reduction in cycle time resulting from use of trolley-powered propulsion.

	Type of mine, example	Depth D (m)	Haulage path length L (m)	Energy needed to complete haul cycle (kWh)*
Scenario 1	Iron ore mine	150	5,000	~ 336
Scenario 2	Cobalt mine	200	10,000	~ 492
Scenario 3	Copper mine	500	15,000	~ 1,043

04

*Scope 1 and 2 carbon intensities of the electrical energy consumed depend strongly on the local energy mix and have thus been set to zero for the purposes of this study.

	Depth D (m)	Haulage path length L (m)	Diesel consumption per cycle (l)	CO_2 emissions (kg)
Scenario 1	150	5,000	105	279
Scenario 2	200	10,000	154	407
Scenario 3	500	15,000	318	840

05

	Depth D (m)	Haulage path length L (m)	Diesel consumption per cycle (l)	CO_2 emissions (kg), Diesel only
Scenario 1	150	5,000	16	41
Scenario 2	200	10,000	26	67
Scenario 3	500	15,000	34	91

06

	Depth D (m)	Haulage path length L (m)	Diesel cycle time (min)	Diesel-assist trolley cycle time (min)
Scenario 1	150	5,000	15.2	9.6
Scenario 2	200	10,000	22.5	13.9
Scenario 3	500	15,000	42.3	23.9

07

simulated depth and length. The purpose is to enable an assessment of operational requirements for an intended haul cycle within three identified regimes:

- Sections without trolley infrastructure where a hauling truck would rely solely on stationary charging technologies to overcome the energy required to complete the cycle.
- Sections with partial trolley coverage but with a residual energy deficit. In such instances, the hauling truck would require a combination of in-motion charging from the trolley line and supplemental stationary charging to meet the overall energy demands of the haul cycle.
- Sections with sufficient trolley coverage to allow for dynamic recharge of the entire energy needed to complete the haul cycle.

In the simulations, it is further assumed that the truck is equipped with a 1.5 MWh battery and that the recuperation of braking energy is enabled during downhill operation.

4. Battery with stationary charging

Stationary charging plays a pivotal role in the decarbonization of mining trucks. It involves strategically placing temporarily fixed stations along haul routes to efficiently recharge or swap truck batteries. Ideally, stops are scheduled and placed such as to minimize downtime. While widely adopted for passenger cars and buses, the application of this technology in mining haulage – particularly open-pit – poses distinct challenges regarding feasibility and economic viability. In this context, the primary challenge arises from the significant energy demand for transporting materials out of a pit. Under these circumstances, batteries must store all the energy needed to bridge the distance and elevation between two charging stations. Assuming one charging station along the haul cycle, this implies ensuring sufficient coverage for a truck to safely travel from and to material handling and charging points.

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Charging stops are scheduled and placed such as to minimize downtime.

To assess the influence of stationary charging, →10 shows productivity measured in tonnage of material transported per day. Assuming 21 operating hours and 290 t of materials hauled per cycle, the simulated productivity is plotted against the charging power of a simulated stationary charger for a mining truck equipped with a 1.5 MWh battery. Again, the braking energy is recuperated to recharge the battery during downhill operation.

Study of payload classes

While the previous section assumed a 290 t payload truck model, this section will analyze the impact of payload on energy consumption per haul cycle. It must be noted that for the different payloads studied here, mostly only diesel and diesel-trolley propulsion technologies are commercially available.

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08 Diesel consumption in liters per haul cycle as a function of the proportion of the ramp equipped with a trolley line.

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09 Energy balance over a simulated haul cycle assuming maximum charging power of the battery while on trolley.

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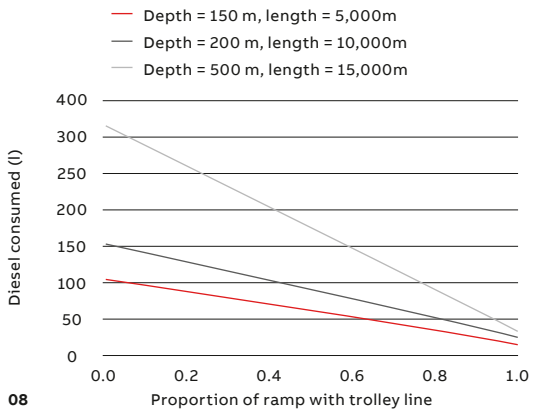
10 Productivity in metric tonnes of materials hauled per day as a function of installed charging power.



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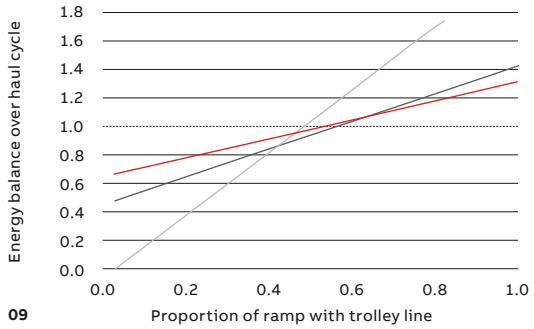

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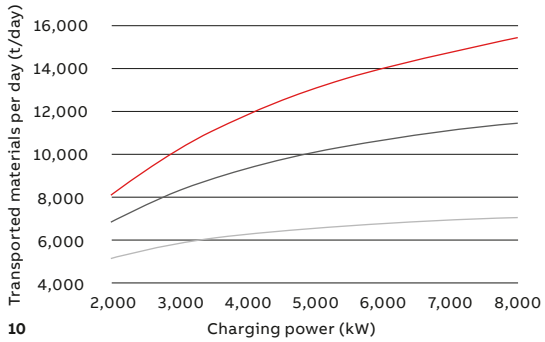

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Payload	Simulated mine type	Depth D (m)	Haulage path length L (m)	Energy per haul cycle (without recuperation) (kWh)	Possible recuperation energy (kWh)
100 t	Iron ore	150	5,000	118	24
	Cobalt	200	10,000	172	27
	Copper	500	15,000	352	84
240 t	Iron ore	150	5,000	261	53
	Cobalt	200	10,000	381	60
	Copper	500	15,000	791	185
360 t	Iron ore	150	5,000	387	74
	Cobalt	200	10,000	566	82
	Copper	500	15,000	1,163	256

11

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11 Since vehicle input parameters, such as the rimpull propulsion curves, frontal areas, or specific energy efficiencies, depend on the engineering of truck models, the results shown are approximate for the respective payload class.

Diesel-trolley technology makes it possible to linearly reduce diesel consumption and CO_2 emissions dependent on the installed trolley line length. Going one step further, replacing the diesel engine with a battery pack offers the possibility of also recuperating braking energy during downhill operation. These potential recuperation gains are illustrated in →11.

If this technology is paired with a trolley infrastructure to supply energy while moving, continuous operations can be achieved in cases where the energy supplied to the battery when connected to the trolley line is sufficient to run on the off-trolley segments. In the current study, it has been determined that, to sustain the operation, a minimum of around 60 percent of the uphill haulage path must be equipped with a trolley system. If determined to be feasible given the mine's operational constraints, in many cases it will be economical to install longer trolley systems because the energy cycled though each truck's battery is further reduced, extending its lifetime, and thus reducing cost.

When using stationary charging for electric haul trucks, flexibility is increased, but productivity is reduced because trucks must stop for recharging. However, with higher-powered charging infrastructure, this problem can be mitigated.

—

Thanks to its simulation tools application, ABB can assess the feasibility of a solution over the life of a given mine.

Nevertheless, one challenge lies in the fact that key parameters of new technologies, such as costs and performance, still have uncertainties. This applies particularly to truck technologies that have not yet been commercialized.

All in all, many technology-related questions remain, such as: the choice of battery technology, battery capacity, and truck payload size; the choice of where to place trolley lines and stationary charging infrastructure and related installed capacity; and predictions of the number of trucks needed. However, by taking operational and infrastructure constraints into account with the simulation tools application, ABB can address these questions during the early phases of a project from a technological and economic point of view and assess the feasibility of a solution over the life of a given mine. •

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MASTERING COMPLEXITY WITH AUTOMATED GRID DESIGN AND ANALYSIS

Greener grids

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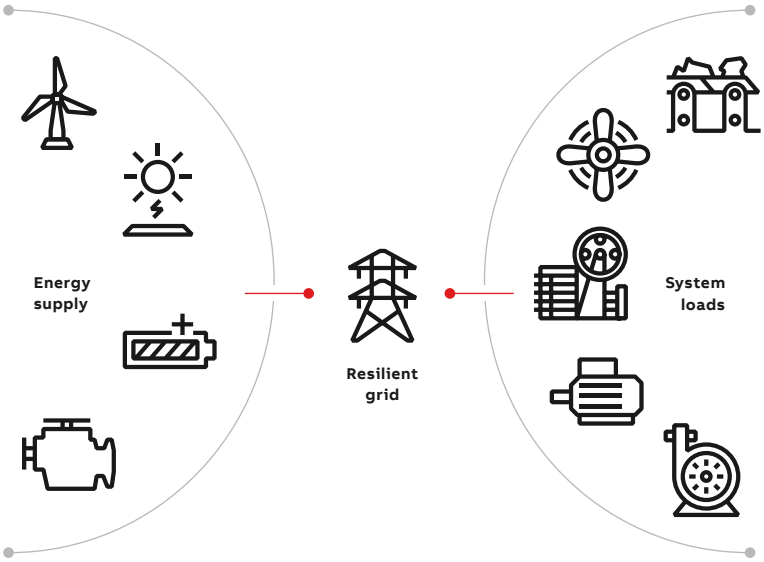
How can energy intensive industries, such as mining, meet sustainability goals? ABB is evolving its industrial grid design toolbox to enable automatic analysis of various load, supply, and potential fault scenarios in the industrial power grid, thereby assisting engineers, designers, and operators in making design and operational decisions.

By merging detailed models of consumption, equipment and operations with historical data on renewable energy, ABB´s mine electrification framework, ABB eMine™, efficiently optimizes the integration of renewable power sources into industrial settings – particularly in the mining industry.

To reach worldwide sustainability targets, the integration of renewables is of paramount importance. This is particularly critical in industries such as manufacturing, mining, hydrogen production, and data centers, which are known for their substantial energy needs. Transitioning these industries to operations based on renewable energy is not only about meeting their high energy demands but also about aligning these efforts with further targets such as carbon emission reductions and sustainability. The availability of renewables at any given industrial plant varies significantly based on daily and seasonal variabilities. This means that each installation must be individually designed to meet the specific needs of its industry. Current estimates foresee renewable sources supplying 45 to 50 percent of global electricity generation by 2030, and between 65 and 85 percent by 2050 [1].

However, integrating renewable energy into the industrial power grids of these industries presents a set of unique challenges, because each industry exhibits complex operational dynamics that lead to intricate load changes. The variabilities of renewable energy sources further escalate this complexity, making the analysis and design of power grids challenging. Moreover, to ensure



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01 Industrial system grid layout based on renewable energy integration.

the smooth operation of any given industrial site, there must always be a balance between multiple energy sources and the overall energy-consuming system →01. In almost all cases this requires a continuous power supply all year round. In addition to the challenges on supplies and loads posed by intermittency, an increasing number of applications utilize non-linear equipment, which adversely affects power quality through harmonics and power factor issues. As a result, poor power quality impacts asset health and performance, resulting in asset failure, diminished or halted production, and eventually plant financial losses.

—
ABB's approach improves the grid layout design process by incorporating an adaptive feedback loop.

To address these challenges, industrial power grids must efficiently and reliably handle a mix of conventional and renewable energy sources and accommodate diverse operational scenarios ranging from steady state to transient conditions. Furthermore, the scarcity of skilled professionals in many industrials domains, combined with the imperative to integrate user requirements early in industrial power grid development, emphasizes the urgent need for innovative and efficient design solutions. This need is further compounded by the absence of automated solutions and the lack of accessible and useful data, which significantly delays the incorporation of renewables into systems. The resulting prolonged integration periods can lead to substantial additional costs, delays and intensified challenges associated with renewable energy adoption.

Detailed simulation models and advanced framework

In today's industrial power grids, understanding the intricate dynamics of equipment energy consumption is essential for renewable energy integration, increasing operational efficiency, and reducing costs. To better support the grid design and corresponding analysis, ABB sets out to provide an in-depth analysis of energy consumption in industrial settings by precisely modelling different assets. These models can capture the unique profiles from diverse stationary systems, such as motors and charging stations, as well as from mobile assets such as trucks.

ABB also considers how dynamic changes in plant operations affect models. For this purpose, a sufficiently generic modeling framework is used to capture physical effects across different time frames. Additionally, industrial plants often operate assets from various manufacturers, and because data and expertise are valuable, it is crucial to keep the models' implementation details confidential. To tackle these issues, ABB uses the interoperability standardized Functional Mockup Interface (FMI) concept, allowing for the combination of models from different manufacturers. Functional Mockup Units are simulation model files conforming to the FMI standard, comprising only compiled code. This allows the protection of model integrity as well as the intellectual property of sources. The models and simulation framework facilitate the creation of load profiles for grid design and seamless integration into the grid analysis module.

Automated industrial power grid design

With these challenges in mind, ABB has developed an automated power grid design and analysis framework that is specifically tailored for modern industrial power grids and is focused on the challenges encountered during renewable energy integration. As illustrated in →02, this solution leverages advanced optimization theory and thorough analysis of power grid conditions to streamline the design process, enhance operational efficiency and reduce the costs associated with integrating renewable energy.

Indeed, the integration of renewable energy is the essential ingredient in achieving truly sustainable systems. However, as many users have discovered, integrating renewable energy into industrial energy systems often necessitates

OPTIMAL TECHNO-ECONOMIC DESIGN & ANALYSIS

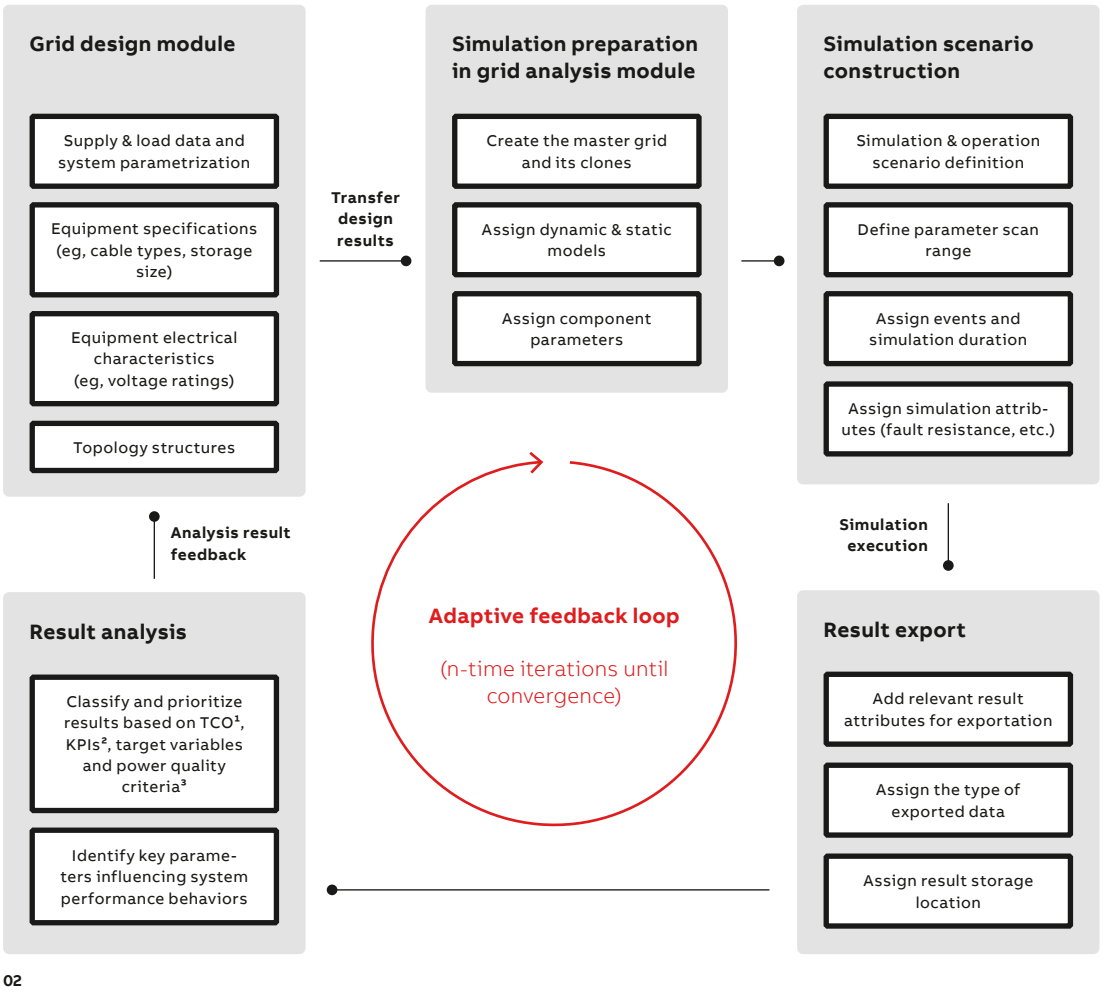
—
02 Workflow in an optimized techno-economic grid design & analysis solution

—
03 Example of the application of the grid analysis approach to the mining industry.

[1] TCO: Total cost of ownership

[2] KPI: Key Performance Indicator

[3] Power quality criteria: Power quality criteria refer to the set of standards and guidelines used to evaluate the stability and reliability of the electrical power. These criteria cover various aspects of power supply, including voltage/frequency stability, power supply continuity, harmonic distortion, power factor, etc. High-quality power is essential for the smooth operation of industrial equipment and for reducing the risk of operational disruptions.



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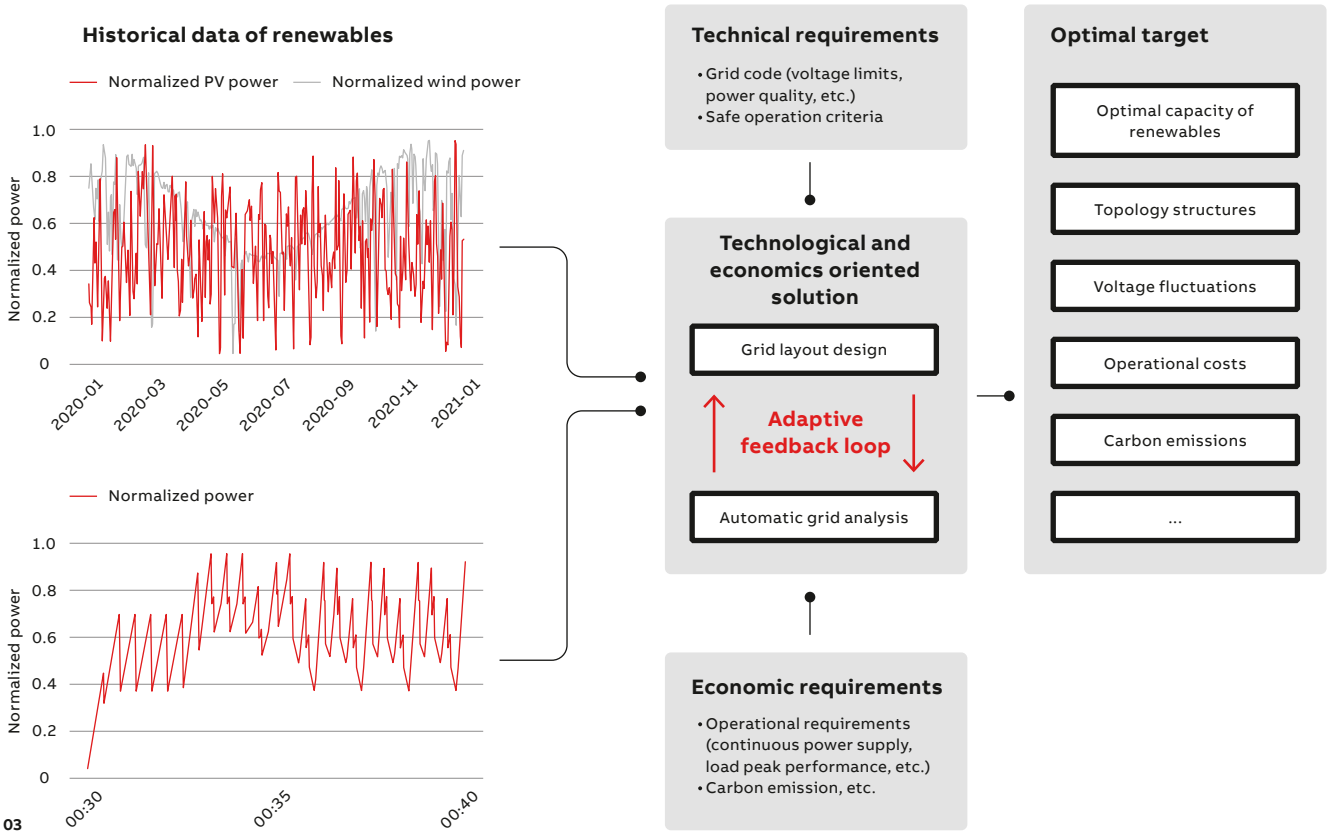

03

upgrades or modifications to the existing power grid to accommodate complicated load dynamics and renewable energy fluctuations. ABB addresses this challenge by developing a comprehensive automation of grid design solutions tool suite. This innovative approach improves the grid layout design process by incorporating an adaptive feedback loop informed by dynamic analysis results.

The process begins with collecting data and user-specific requirements, including key performance indicators such as building costs and carbon emissions. This are used to generate an optimal power grid layout that takes elements such as voltage ratings and cable selection into account. This layout is achieved by solving an optimization model that adheres to grid codes and static operational safety margins. Optimized grid design results can then be read by current mainstream power system analysis software. The system automatically generates various simulation and operational scenarios for transient behavior analysis, such as switching and faults. In addition, the feedback loop adjusts the design through iterations based on transient analysis, thus refining its layout solutions.

The method's advantages are manifold and significant. Compared to the traditional approach, it can dramatically reduce design time, thus streamlining processes. In addition, the combination of steady-state and dynamic transient analyses ensures high safety and accuracy, guaranteeing that the grid layout meets diverse operational requirements under various scenarios. The adaptive feedback loop further reinforces reliability, satisfying both static and dynamic safety criteria. Importantly, the method's design is reusable and scalable, making it applicable to a range of industries such as mining, marine and port operations, as well as hydrogen production plants.

Industrial power grid performance optimization with automatic transient analysis

Today, the prevailing methodologies employed for the dynamic analysis of power grids predominantly entail the construction of a single-line diagram (SLD) within the relevant simulation tool, followed by the execution of simulations to examine grid behavior. However, there are significant drawbacks to this approach, as it takes a long time to manually set up grids – a process that can lead to human error – especially in cases with many grid components.

To avoid such drawbacks, a comprehensive approach for executing grid analysis is needed – one that includes automatic model creation and modifications to the grid setup. With this in mind, the analytical approach developed by ABB for power grid analysis delves into transient grid dynamics. Initially, the grid layout design results are imported as inputs of the simulation. All pertinent grid information, encompassing the type and electrical characteristics of each grid component, as well as the topological structure, resides within a data exchange universal format file as a bidirectional interface designed specifically for data transfer among applications. This file format is universally supported by both the grid layout design and grid analysis modules, facilitating a seamless transfer of data without necessitating manual implementations of the grid. This aspect is particularly important when dealing with extensive grids or those

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A comprehensive approach to grid analysis with automatic model creation and modifications to the grid setup is needed.

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undergoing structural changes due to topology modifications.

This initial phase marks the inception of the first step of automatic grid analysis, which offers notable advantages. After importing grid attributes, a master grid aligned with an SLD is automatically generated. Clone grids, modified from the master grid by altering component parameters or setups, are created with various dynamic asset models for transient behavior studies. In addition, the required dynamic simulation events, including load energization via switching and fault events, are generated and executed automatically.

Analyses based on simulation results are then looped back into the grid design module, enabling the generation of a revised design if needed. This iterative process highlights the integration of analytical insights and automation, fostering an efficient and informed approach to power grid stability analysis.

This automated open interface opens the door to optimizing grid operation and analysis. This process involves sweeping through component parameter ranges and different operation scenarios to verify grid stability and optimize for a target variable, such as operational costs.

Most importantly, the techno-economical calculation functionality in this proposed simulation module enables investigation into grid expansion strategies, power quality assessments, and service interruptions, all of which further incorporate optimization decision criteria for resource allocation and profitability.

Applying grid design & analysis solutions to mining industries

The mining and mineral processing industry offers an ideal application area for ABB's solution. Facing high energy demand and significant pushback due to its environmental impact, this industry urgently needs to integrate renewable energy sources such as solar and wind power to mitigate greenhouse gas emissions. Given the complex and dynamic power requirements of mining equipment, particularly the accelerated adoption of electric trucks and the associated infrastructure for stationary (battery charging), and dynamic energy transfer (vehicle propulsion), the complexity of elerictrical grid design and analysis in this area cannot be underestimated.

Yet, the absence of effective automated solutions hampers the smooth integration of renewable energy, thus slowing down the journey toward sustainability. ABB eMine™ answers this challenge by evolving its approach for mining grid design in such a way as to be able to efficiently address the related complexities and significantly contribute to more sustainable and effective industrial practices. Additionally, by utilizing the automated grid analysis method, various load, supply, and potential fault scenarios can automatically be analyzed in the power grid, thereby assisting engineers, designers, and operators

ABB eMine™ supports the integration of renewable energy thanks to advanced mining equipment models.

in making design and operational decisions. This is accomplished by constructing detailed energy consumption and simulation models for a range of mining equipment. By merging this with historical data on renewable energy data →03, ABB can efficiently optimize power grid solutions for the integration of renewable energy.

Advanced analysis of this type offers optimal configuration solutions for mining grids. These solutions, informed by the renewable capability design and equipment energy consumption analyses, serve as essential inputs for the subsequent phase of dynamic behavior verification, thus ensuring system reliably without compromising efficiency.

In addition, the grid analysis approach automatically evaluates various operating scenarios, empowering mine operators with critical insights for informed decision-making. The solution will further form the basis and provide potential for developing advanced features in other mining areas, such as optimizing the sizing of battery storage systems and electric truck fleets.

All in all, by leveraging ABB's process automation mining expertise, its industrial grid and analysis solutions enhance the offering around ABB eMine™ and support informed investment decisions, thus pointing the way to improved decarbonization and cost-efficient operations. •

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Consistency in opacity and whiteness are signs of quality in paper production.

Color monitoring is an integral part of the production process.

ABB has developed a highly precise color-measurement system using LED lights and color sensors.

01

— 01 It is vital that paper color is kept tightly controlled from one reel to the next.

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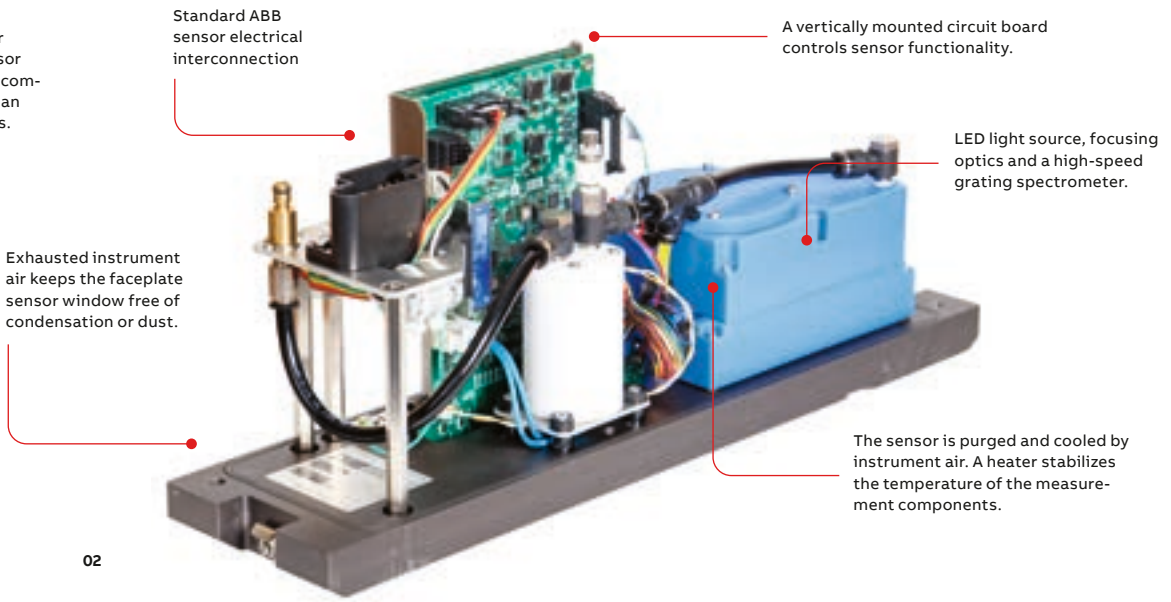
Color – the term is used here to also cover brightness, opacity and whiteness – is a quality of paper that few people consciously consider, yet it plays a crucial role in paper manufacturing and use. For example, print quality, readability and visual aesthetic appeal are all significantly affected by paper color. A company's brand recognition may rely on the color of the paper they use and color is important, too, when specific shades are required for security documents such as passports or identification cards →01.

Online monitoring of paper color during production is, therefore, critical for ensuring product consistency and, thereby, sellability. The online instrumentation involved must have the performance characteristics needed to maintain a stable process with minimal off-specification product – especially during shade changes or when rapidly moving the process to a different grade of paper (heavier, lighter, etc.) However, papermaking processes present a unique challenge for color measurement due to the widespread use of optical brightening agents (OBAs) that fluoresce in the blue region of the visible spectrum to increase apparent whiteness and brightness.

A colorful history

Having installed its first online color sensors on paper machines in the early 1980s, ABB has a long history of innovation in this field. To date, the laboratory and online color instrumentation

02 The ABB High Performance Color Measurement sensor module. It is more compact and lighter than incumbent designs.



02

approaches pursued by ABB and others have been dominated by designs based on gas-discharge or tungsten-halogen lamps. While these technologies are well-proven and well-standardized, they have inherent drawbacks regarding lamp lifetime, spectral degradation over time and pulse generator charge-up time (which limits measurement rate). Another significant disadvantage is the need to filter lamp output to control ultraviolet (UV) content so that OBA effects can be taken into account. Here, a UV filter has to be physically moved in front of the discharge lamp, severely limiting the rate at which measurements can be made.

From lamps to LEDs

In recent years, LED technology has advanced dramatically, especially regarding stability, repeatability, spectral range and optical power. Furthermore, as LEDs are discrete emitters with a variety of well-defined spectral ranges, it is possible to select individual emitters that span separately the UV and photoptic regions of the spectrum. In this way, LED emitter pairs employed in a color sensor can be sequenced to produce alternate UV-included and UV-excluded illumination modes many times every second to give an almost continuous stream of color data on a moving web of paper. Thus, the necessity to physically move a UV filter, as described above, is eliminated.

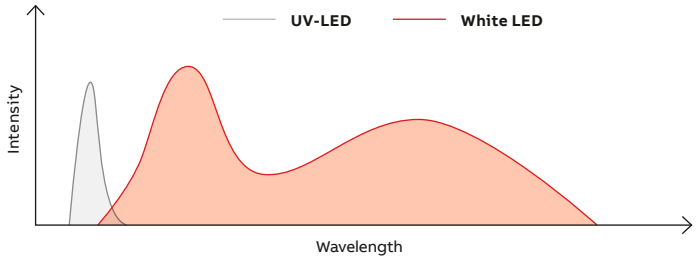
The sensor gives unprecedented color measurement resolution, with greater accuracy and lower short-term variability.

ABB's High Performance Color Measurement sensor embodies this approach, using modern LED technology and a high-speed spectrometer that can measure the colorimetric properties of moving paper while scanning across the sheet during production →02. The sensor has been explicitly designed to overcome the many challenges encountered when measuring fluorescent and non-fluorescent paper in an industrial environment.

Sensor design

The ABB High Performance Color Measurement sensor module is designed to be mounted on either side of the paper or both sides of the paper, typically on an ABB Network Platform scanner that traverses it across the paper sheet, measuring colorimetric properties, in some tens of seconds. A backing tile module (BTM) is mounted on the opposite side of the process. The BTM allows colored tiles to be mounted in the optical path of the sensor for measuring supplementary colorimetric and optical properties, such as opacity (see below).

In the sensor, a white LED and blue-UV LED are sequenced – both on, then only white on – to produce UV-included and UV-excluded illumination modes. With both LEDs off, a third mode can be invoked optionally for baseline measurements to account for the intense extraneous light sources often found around paper machines →03.



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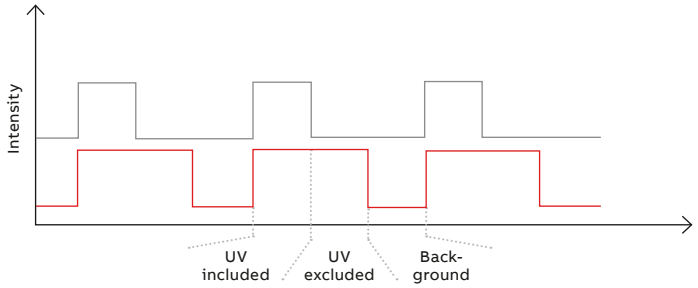

03b

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03 LED sequencing.

03a UV-included, UV-excluded and baseline illumination scheme.

03b Spectral characteristics.

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04 The BTM rotates various tiles at the side of the paper opposite to the sensor module.

A toroidal mirror produces an undirected annular illumination pattern on the paper at 45°, focused to a 10 mm spot. Light scattered and reflected normal to the paper is gathered and directed via a mirror to the spectrometer (thus following the favored 45°/0° design).

With up to 50 full readings of both UV-included and UV-excluded per second, the sensor gives unprecedented color measurement resolution in the machine- and cross-direction of the paper machine, with greater accuracy and lower short-term variability than traditional approaches. The sampling rate is 10 to 100 times faster than gas-discharge lamps and data is averaged continuously to deliver better measurement information for control applications. This high sampling rate means each measurement sent to the host is an average of hundreds of readings across the sheet, which, especially in a scanning application, drastically reduces color process noise from moisture and temperature streaks.

With more frequent and continuous measurement, paper manufacturers benefit from increased precision, leading to more consistent color and improved final product quality. The sensor enables manufacturers to precisely control color while minimizing off-specification product and improving shade consistency, as well as reducing the use of expensive fluorescent whitening agents, dyes and pigments.

Backing tile module design

As described above, the BTM is located on the opposite side of the process to the color measurement module. The BTM features a patented tile enclosure mechanism that helps automate sensor calibration, standardization and check sample routines to minimize operator intervention and ensure long-term sensor capability. The BTM features a six-tile carousel: The white backing tile facilitates continuous color measurement, while a black backing tile enables the sensor to make “infinite thickness” color calculations (a method patented by ABB) →04. To ensure long-term sensor stability, black and white standardization tiles are included to help the color sensor correct for variables that may affect accuracy (such as dust or dirt build-up). In the absence of the web, tiles are used to standardize the reflectance measurement and check the instrument’s performance over time against an internal standard. An internal check sample automatically verifies and certifies online sensor performance.

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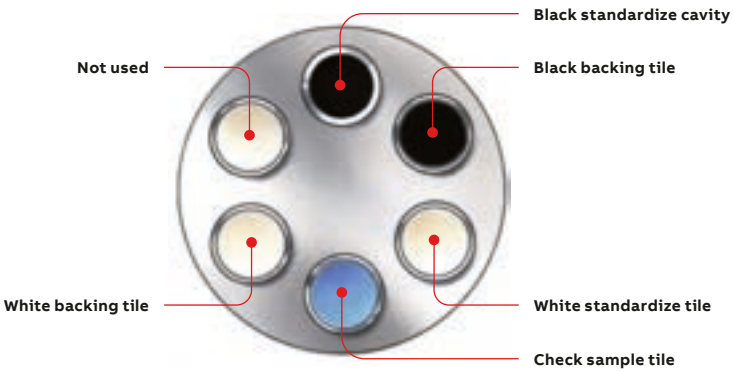
Manufacturers benefit from increased precision, leading to more consistent color and improved final product quality.



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The BTM utilizes a high-velocity air stream – a so-called Bernoulli hold-down – to stabilize the paper web passline. This hold-down eliminates sheet flutter and enables non-contact color measurement.

Color correlation

The sensor has been extensively tested to ensure correlation with both laboratory instrumentation and existing gas-discharge online instruments. In particular, the performance of UV-included

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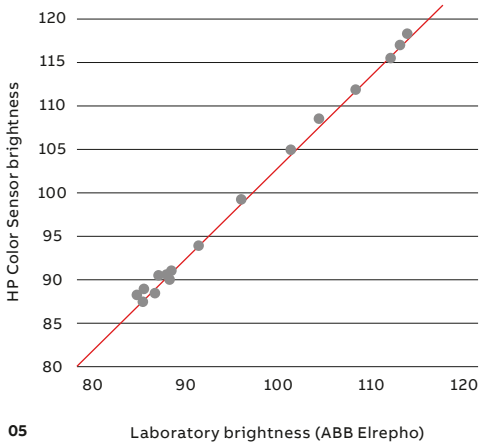
05 Comparison of ISO brightness (ISO 2470) between ABB Elrepho laboratory instrument and High Performance Color Measurement sensor on fluorescent standard samples.



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and UV-excluded measurement algorithms were rigorously examined to ensure accurate performance on fluorescent materials.

→05 shows data for a set of fluorescent plastic samples measured by the sensor and a laboratory instrument (a Lorentzen & Wettre Elrepho, calibrated with traceable standards provided by the manufacturer). This plot compares the ISO brightness of the samples measured in UV-included and UV-excluded modes, based on a D65 standard illuminant. The LED sensor shows excellent correlation in both illumination modes, despite the difference in illumination sources (LED versus xenon).

When dealing with color, L*a*b* is a color space that is very often used. This color space was defined by the International Commission on Illumination (CIE) in 1976 and expresses color as three values: L* for perceptual lightness and a* and b* for the four unique colors of human vision: red, green, blue and yellow. The two measurement sets (laboratory device versus the color sensor) for each of the three color space values lie almost on top of each other.

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A modular design with no moving parts in the main module enhances reliability and lowers costs.

It should be noted that LED spectral characteristics differ somewhat from the standard illuminants defined by the CIE, which means LED devices need more source correction than gas-discharge-based instruments.

The High Performance Color Measurement sensor has also been trialed on several paper machines, where it tracks other means of measurement very well.

Easy maintenance and upgrade

The sensor features a lightweight, compact, modular design with no moving parts in the measurement module, thereby enhancing reliability and lowering maintenance and lifecycle costs. The lifetimes of the LED sources are many times longer than those of lamp designs and major parts can be replaced without recalibration. Safety is also improved as high-voltage pulsing and powerful capacitors have been eliminated. Real-time health reporting to the host is provided.

The High Performance Color Measurement sensor can be applied to the top or bottom of the web or to both sides and is designed for a quick and easy upgrade path as the measurement module is plug-compatible with ABB's Smart Color sensor and is also fully compatible with the previous generation Smart BTM. The sensor works on ABB's Network Platform scanner in conjunction with ABB's Multivariable Color Control to minimize off-specification product and reduce shade change and start-up times. The sensor's new Color Profiles feature enables the optimization of white top, size press and coating operations.

An even brighter future

As LED brightness and spectral characteristics improve, the sensor can be further enhanced. Additionally, the sensor's high measurement rate will allow the separation of machine- and cross-direction information in the signal, opening up more opportunities for improved color control that were not possible with slower gas-lamp devices.

Future work is likely to also include the provision of control algorithms that fully exploit the unprecedented resolution of the sensor and enable papermakers to automatically and precisely rapidly change to a target shade and deliver superior consistency of color, brightness, fluorescence, opacity and whiteness in their products. •

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HIGH-PERFORMANCE ONLINE MOISTURE MEASUREMENT OF PAPER

Reflecting on paper moisture

ABB's HPIR-R moisture sensor adds another high-speed moisture sensor to complement the successful HPIR-T sensor. HPIR-R measures paper surface moisture and temperature using infrared spectroscopy in some of the most challenging and extreme environments in the pulp and paper industry.

Measurement of moisture is an important part of monitoring in paper production.

Infrared light is used for non-contact measurement of surface moisture.

ABB offers the fastest moisture-measurement on the market.

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01 ABB's new HPIR-R moisture sensor traversing the middle of the paper sheet. The sensor delivers high-speed, continuous moisture readings as it scans.

Papermaking has a history that stretches back over thousands of years, but only in the past few decades have effective tools for paper quality evaluation become available. Even as late as the 1920s, companies relied upon the innate skills of operators who checked paper uniformity by sight, reel hardness with a stick and moisture content using the effect of static electricity on their arm hair.

The moisture content of paper was an early target for innovation and in the late 1920s, electrical conductivity techniques were employed to measure it. These primitive, "better than nothing" approaches gave a good indicator of moisture but provided very little in terms of trending, cross-sheet profiles or control capability.

The fundamentals of a paper production process require moisture as a key metric to see, firstly, the moisture content of the process and secondly, to combine with a total mass measurement to partition dry weight and water weight. Dry weight represents the weight/cost of feedstock applied; moisture/water weight the amount of drying (and associated energy costs) needed to achieve an optimal setpoint at key locations in the papermaking process.

Blink and you'll miss it

Water and the organic materials within paper webs exhibit strong vibrational absorption bands across the electromagnetic spectrum's infrared (IR) region. As a result, moisture concentration is typically estimated by differential absorption measurements in adjacent moisture and cellulose combination bands within the near-IR (1.7 to 2.2 µm). The IR approach has long been favored by moisture sensor developers – IR has a unique ability to measure from the lightest tissue to boards, from zero moisture up to the saturation limits of paper.

The signal processing used in ABB's older generation and competitors' versions of such IR moisture sensors exploits amplitude modulation and subsequent demodulation of the IR radiation to suppress any background phenomena that may influence measurements and overcome fundamental detector limitations. However, this modulation is usually accomplished by a mechanical IR beam chopper, which means, rather like a blinking eye, the system only catches measurements when the eye is open. This situation has disadvantages incompatible with many of today's high-speed production processes. For example, the measurement speed is limited by the modulation frequency (the Nyquist limit) and the ability of the detector electronics to pre-filter and demodulate the signal.

ABB's new HPIR-R sensor adopts a fundamentally different [1] and simpler approach to signal processing for IR moisture measurements. Instead of using amplitude modulation of the measurement beam, the instrument continuously delivers IR energy to the web process, ensuring that the instrument measures at the maximum potential speed (limited only by the photovoltaic detector characteristics) with the best signal-to-noise ratio and speed available in the market.

HPIR-R sensor design

The HPIR-R module contains a tungsten halogen lamp that provides constant and intense broadband visible light and an abundant and cheap source of IR →01-03. The module also includes a shutter that can be rapidly inserted in front of the lamp for a short time to block IR energy from reaching the web so that a normalization offset – a combination of electronic offset and background optical signal – can be established. So that no process data is lost, this background normalization is performed when the scanning instrument pauses to turn around after every five or more scans across the paper sheet. The shutter is also closed when the sensor is "parked" by the side of the sheet. During normal operation,

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The sensor continuously delivers IR, thus measuring with the best signal-to-noise ratio and speed in the market.

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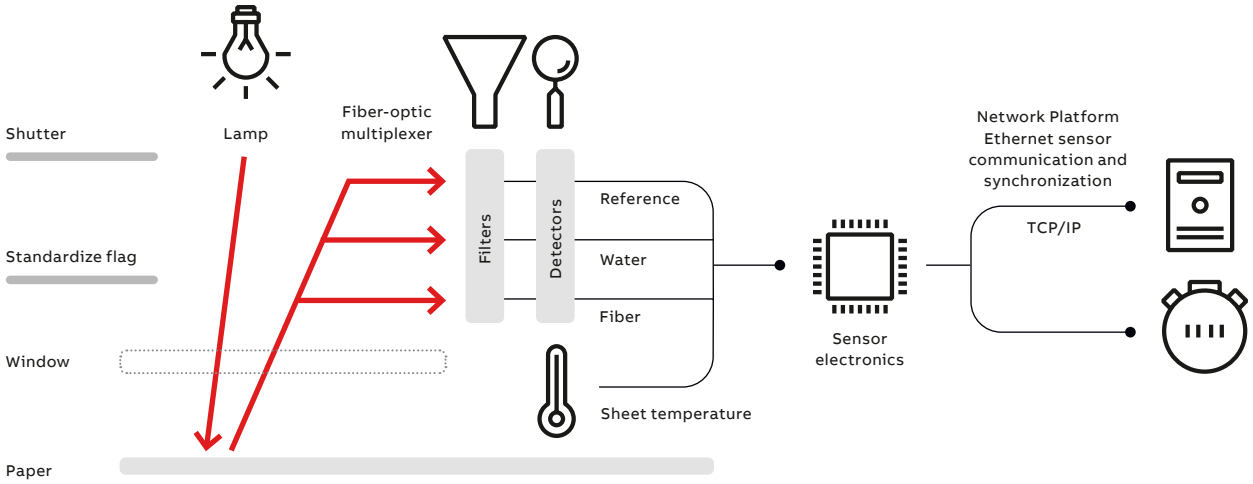

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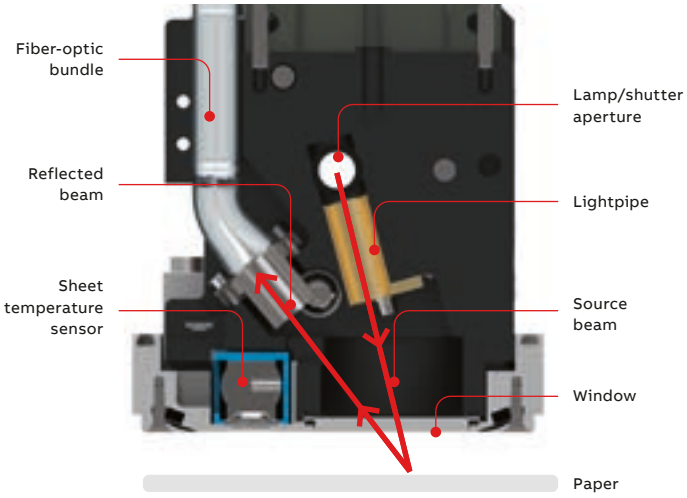

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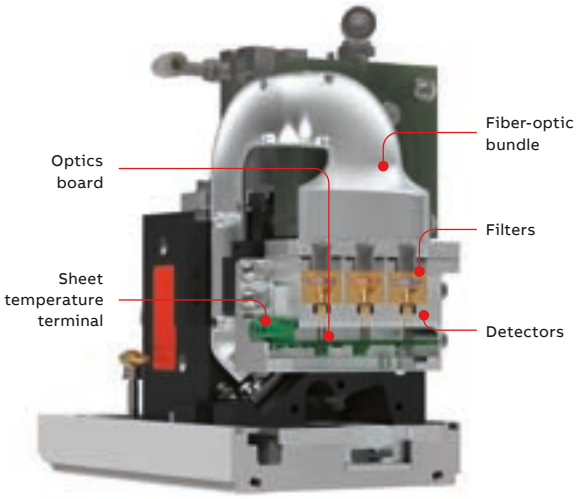

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02 Non-modulating technology enables ABB's HPIR sensors to behave like an unblinking eye.

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03 HPIR-R sensor.

03a Principal components, side view.

03b Principal components, oblique view.

the shutter is always open, allowing the high measurement rate that is HPIR-R's defining characteristic.

HPIR-R's optical components efficiently concentrate and guide the source lamp's IR energy toward the paper surface through a window →04. The reflected energy is picked up by each of the three detectors (detecting a specific wavelength using an optical filter) and the light absorbed at each wavelength relative to a reference wavelength will be indicative of the concentrations of water and cellulose within the paper surface.

The detector consists of a fiber-optic multiplexer with a fiber-optic bundle (some 3,000 individual fibers) structured as a random network within the multiplexer to deliver input energy randomly to three termination ports. Fiber optics are a unique enabling technology for ABB infrared measurements. They are highly efficient, vibration- and temperature-insensitive, robust and allow a very simple, compact and lightweight device design. The flexible optical fibers allow optoelectronic components to be mounted in an optimal configuration for product packaging and temperature control. Other approaches involving

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Fiber optics are highly efficient, vibration- and temperature-insensitive, robust and allow a compact and light design.

mirrors, beam splitters and diffusing spheres are less space-efficient and susceptible to many environmental factors.

At each of the termination points, an IR band-pass filter is used to select the three near-IR wavelength bands of interest (reference, water and cellulose). Signals are then directed to three photodetectors to produce an electronic signal in proportion to the IR optical power incident on the photodetector. The photodetector signal is then conditioned by amplifiers set at an optimal gain to maximize digitizer resolution. Each detector channel has an equal view of the same spot on the process, allowing for continuous and simultaneous measurement at each wavelength. No backing tile on the other side of the sheet is needed.

All optoelectronic components are housed within a single air-cooled, temperature-controlled enclosure. HPIR-R is designed to operate in temperatures of up to 125 °C to measure moisture concentrations of 0 to 70 percent over a dry web weight range of anything from the lightest ply of tissue to the heaviest board. The measurement has an absolute accuracy of 0.25 percent and a resolution significantly better than 0.01 percent. This sensor is delivered as a single product type with a comprehensive factory calibration suitable for any paper type it will encounter, which makes the sensors fully interchangeable.

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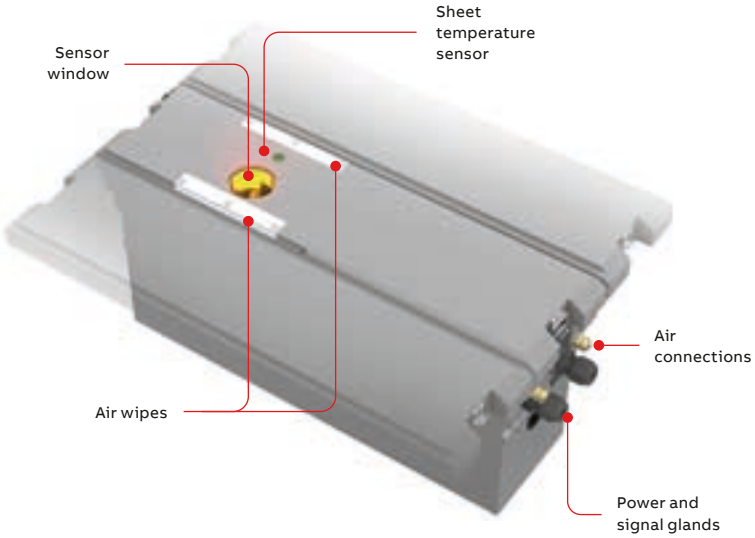
04 The process-facing side of the HPIR-R sensor, showing the window through which the sensor acquires measurements.



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HPIR-R is field repairable, which, coupled with its insensitivity to dust and disturbances, enables high uptime and lower total cost of ownership than similar solutions. Customers can be located deep in a forest close to raw materials and energy or adjacent to city centers, so field repairability is crucial. Most repair steps are part swaps requiring only hex wrenches and a few minutes. Furthermore, as scanners are embedded deep in the paper machine, ABB outlines a preventative maintenance program (every two years) that can be synchronized with machine downtime.

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HPIR-R produces up to 5,000 fully integrated, statistically independent moisture measurements per second.

Compensating for extraneous IR effects
The hot web process will also emit broadband IR energy. The irradiance and spectral characteristics of this emission will depend on web temperature. To “remove” this effect from the main IR signal, HPIR-R has an integrated auxiliary IR pyrometer that provides a simultaneous, separate web IR-emission measurement. This reading is also used to compensate the moisture measurement for other background IR effects. In other words, HPIR-R gives the papermaker the bonus of a simultaneous temperature measurement, providing additional insight into their paper surface characteristics.

Fastest moisture measurement on the market
HPIR-R produces up to 5,000 fully integrated, statistically independent moisture measurements per second. This rate is unprecedented and unmatched in the industry. For comparison, HPIR-R delivers 83 times more (100 times more in 50 Hz systems) data points than its 1973 equivalent, with a spatial measurement resolution of just 6 mm – the same dimension as the fingertip measurement of the early days of papermaking.

Part of the ABB Ability™ Quality Management System, the HPIR-R IP-format output is fully digital, which ensures signal integrity. The torrent of data generated can immediately be sent through the mill’s fiber-optic backbone to an edge server, quality management applications and the cloud. The high-speed measurements are accompanied by a rich set of diagnostic

data that is ideal for analytics to inform onsite or corporate-level decision-making. HPIR-R is applicable to all ABB Network Platform scanner types, ready to be used to measure publication grades, graphic papers, board, tissue, packaging, coated products, colored products, specialist and recycled grades.

Cost and energy savings

The unprecedented speed and accuracy of the moisture measurements delivered by HPIR-R's patented technology lead to optimized drying, decreased steam usage, significant energy savings in dryer sections and reduced carbon footprint. For instance, changing the steam pressure to create a moisture change of just 1 percent can equate to $400,000 in annual energy savings. The small spot of IR energy used in the sensor provides excellent streak resolution and accurate edge-to-edge sheet measurement, even in the most challenging environments →05.

While the sensor can be placed anywhere, the highest impact location is before a size press, where better precision and accuracy allow

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— 05 The intense IR emitted by the IR dryers at the top of this sheet draw has no effect on HPIR-R, seen here at the back of the sheet with its measurement spot at the front.

— 06 HPIR-R is positioned at points in the process where it has the most impact. Often, the size press is the best location.

operators to raise the moisture target, giving optimized starch/sizing pickup and reduced drying energy demand →06. Another high-value location is after the wet press section, where the sensor enables operators to adjust press loadings to improve the moisture profile and increase sheet dryness going into the dryers. In addition to energy savings, this fine-tuning also gives higher sheet strength in this sensitive area of the machine, meaning improved runnability and sheet break recovery.

Confidence to raise moisture targets and tighten tolerance bands

With the fastest moisture measurement available today, HPIR-R provides the precise, edge-to-edge measurement that gives operators the confidence to raise moisture targets throughout the process, thus improving profiles and decreasing energy usage.

Further, because the exact moisture levels are known at all times, a tighter moisture target zone can be applied. This improvement immediately translates to significant energy cost savings as it eliminates over-drying some areas of the sheet in the effort to make sure all areas are within their moisture specifications. Moreover, the papermaker can get to on-specification product faster, helping to increase production tonnage, save energy and reduce quality losses.

The data benefits of not blinking an eye

Beyond the basics of moisture control, HPIR-R's unblinking eye enables the global shift whereby companies increasingly adopt Industry 4.0 working practices and the Industrial Internet of Things (IIoT) to serve up all-important operational data. Modern information-based systems thrive on sharing and analyzing data so quality levels can be constantly gauged and compared historically against variations in shift patterns, operator capabilities, seasonal temperature ranges and raw materials, to name but a few.

The user gets on-specification product faster, thus increasing production, saving energy and reducing quality losses.

ABB's HPIR-R moisture sensor adds another high-speed moisture sensor to complement the successful HPIR-T sensor. HPIR-R measures paper surface moisture and temperature using infrared spectroscopy, bringing spectroscopy and high-performance measurement to some of the most challenging and extreme environments in the process industries.

Through the rising steam, recycled residue, vibration and high temperatures of a modern paper machine, HPIR-R peers at the surface of the running paper in the infrared to reveal those invisible "colors" of chemistry. Millimeter by millimeter as it traverses the paper width, HPIR-R builds up data of the surface moisture and surface temperature of the paper at 5,000 measurements each second. Moisture data, combined with basis weight sensor data, also reveals the dry mass of the process.

These data reveal the minute variations of the paper during production, assembled as a digital fingerprint feeding ABB control algorithms with the information needed to reduce the variability of the process and rapidly and efficiently achieve and maintain the desired setpoint. In such a high-speed and energy-intensive process, minute variations accumulate very quickly, so fast detection and response is critical. Control of moisture has been and always will be fundamental to the efficiency and sustainability of paper production.

Transforming ABB's sensors for an era of sustainability and digitization is the challenge. HPIR-R meets this challenge with a compelling, digitally native solution that draws on the best of ABB's long experience and combines it with modern technology to make a product that will address the needs of the papermaking industry in the coming decades. •

Reference

[1] S.P. Sturm et al., "Method and apparatus for on-line web property measurement," U.S. patent, US8148690, April 3, 2012.

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NON-INVASIVE REAL-TIME MELT TEMPERATURE MEASUREMENT PREDICTION

Measuring the melt

In a targeted study, ABB developed and successfully tested an advanced artificial intelligence (AI) model that accurately predicts the temperature of the steel melt within an electric arc furnace (EAF) continuously from the rise in the cooling water. Further development of this innovation will allow the steel industry to better optimize their steelmaking process and promote sustainability, saving energy and lowering emissions.

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It is widely known that the production of steel is associated with high levels of greenhouse gas (GHG) emissions: steel mills globally produce 1.78 Gt of off-gases annually [1]. Without a doubt the carbon footprint of steel is high – in 2018, for instance, for every ton of steel produced, an average 1.85 tons of CO_2 was emitted; this equates to about 8 percent of global carbon dioxide emissions for that year [2]. This reality is in sharp contrast with the increasing customer demand for less carbon-intensive steel production, tightening of carbon emission regulations and the increasing investor and public interest in sustainability [2].

Thus, despite notable challenges, steel production needs to become greener; efforts toward decarbonization, optimizing energy consumption, and other actions are necessary.

Without a doubt, the carbon footprint of steel is high, and yet, customers demand a less carbon-intensive steel production.

The application of advanced digital technologies could help resolve these challenges. With more than a century of experience, ABB focuses on electrification, automation and digital solutions that incorporate advanced data analytics, machine learning (ML) and other AI technologies to help mitigate the challenges faced by metal producers to reduce emissions, optimize energy consumption while improving productivity and lowering costs. Thus, ABB can enable the digital

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transformation of the steel industry to accelerate sustainability. In this work, ABB investigates the application of mechanistic and AI models, specifically Neural Network (NN) modeling, to provide the means to accurately estimate the steel melt temperature in an electric arc furnace (EAF) non-invasively in an effort to reduce outgassing and energy consumption through optimization.

Choosing the right furnace with sustainability in mind

Pursuing a low carbon future in the steel industry begins with the choice of smelting furnace. Two main steelmaking technologies are in use: the conventional integrated blast furnace (BF)/basic oxygen furnace (BOF), the principal method used currently in Europe, and the increasingly popular EAF →01. While integrated blast furnaces produce steel from raw materials such as iron ore and need coal (or coke) to act as a reductant, EAFs can use a wide range of

ABB is using AI to help metal producers mitigate challenges such as optimizing energy consumption and lowering costs.

raw materials such as scrap steel and direct reduced iron (DRI), and hot metal – independent of coal. Not only does the flexibility provided by EAFs help producers to meet market demands

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01 ABB technologies are already improving the efficiency of some of the world's largest electric arc furnaces. Acciaieria Arvedi's record-breaking EAF has a tapping size of 300 metric tons and utilizes a charge mix including hot briquetted iron (HBI), a premium form of DRI.

more quickly whenever the availability of raw materials changes, EAFs are associated with lower carbon dioxide emissions, better resource efficiency, and recycling capabilities. ABB, with its focus on innovative technologies in the metals industry, is actively assessing and developing breakthrough technologies for EAFs, thereby providing technologies to improve operational efficiency and support the steel making industry's pursuit of sustainable low-carbon steel production.

Promoting efficiency too

As with all batch processes, control of process variables, such as temperature, during each stage of the steelmaking process is crucial to ensure maximum productivity while reducing energy use and operational costs. The utilization of non-invasive temperature measurement can help reach these goals.

To promote EAF process efficiency and better control the production of off-gas, it is necessary to monitor the steel melt temperature accurately during the process but this is challenging. Given that the melt temperature can be as high as 1,630 °C or more, it is impossible to install a permanent temperature probe within the EAF. To measure melt temperature the existing practice

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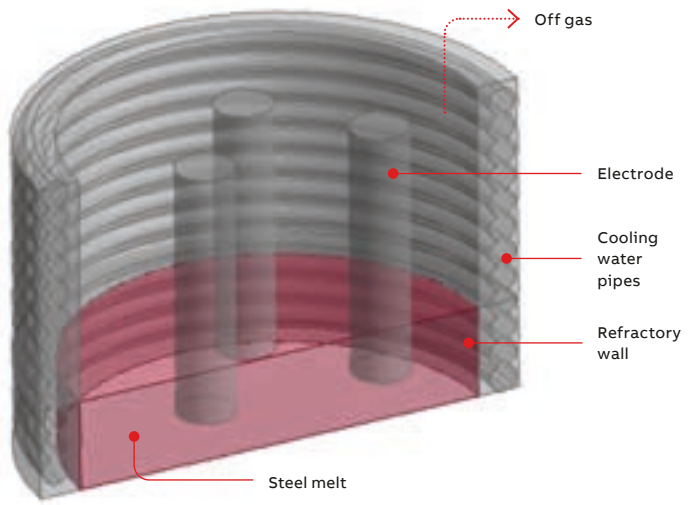
With their focus on innovative technologies, ABB is actively assessing and developing breakthrough technologies for EAFs.

is to introduce a sacrificial sensor into the melt, to record the temperature momentarily and then to discard the sensor. This process is performed once in every production run. The thermal sensor is inserted into the thermowell; the electrodes are powered off during the measurement



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02 Basic schematic of a typical EAF.

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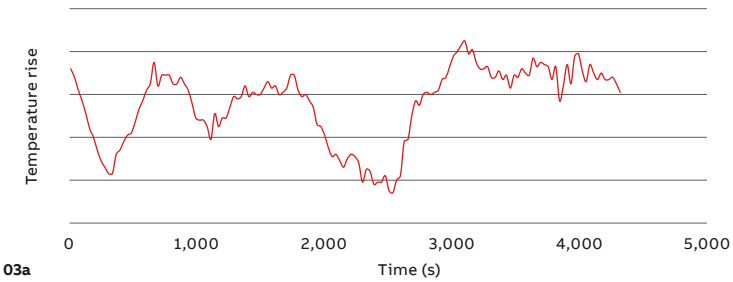
03 Comparison of various temperature measurements and estimations. The temperature axis units have been omitted for proprietary reasons.

03a Cooling water temperature, Tcw, rise vs time is shown.

03b The graph compares scaled Tcw to melt temperature, Tm, which was estimated using a heat balance equation.

process, thereby reducing efficiency, impacting costs and even safety.

To fine-tune the various operational parameters with the objective of saving energy and ensuring quality, it would be necessary to monitor temperature in real-time and not simply once per run. ABB set out to explore a method to do just that: estimate the melt temperature continuously using external temperature measurements and AI methodology at the Process Automation Hackathon 2022 – ABB's annual event designed to showcase innovative ideas in the field of process automation.



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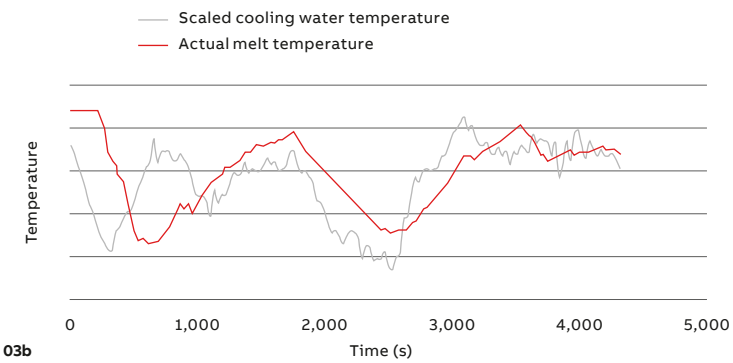


03b

EAF construction and smelting process
Prior to describing the methodologies applied in this investigation it is important to explain how the EAF →01 functions. Using the heat generated by arcing electrodes, steel, along with other feed materials, is melted within an enclosed chamber →02. The firebrick chamber is provided with a refractory lining within which a jacket of water pipes is installed for cooling purposes to protect the refractory lining →02. The gases generated during the cooling are ejected from an outlet at the top of the EAF.

Non-invasive temperature estimation
At the PA 2022 Hackathon, ABB and collaborators examined the idea of whether the melt temperature rise of the melt could be determined based on external manifestations, specifically the temperature rise of the cooling water that circulates in pipes within the chamber jacket. ABB performed an initial proof-of-concept study using measurement data supplied by the customer. The cooling water temperature rise, Tcw, determined by subtracting the outlet water temperature from the inlet temperature, was directly obtained

Experts successfully developed and tested a DNN model that related the cooling water temperature to the melt temperature.

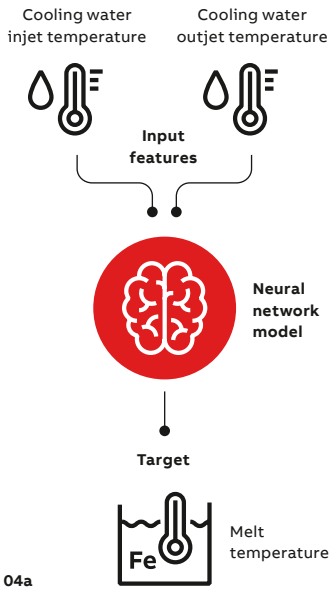
from the plant →03a. Plant data from measurements of the arc power, oxygen flowrate, etc. were also supplied. The melt temperature, Tm, was estimated in real-time using a heat balance model performed in python →03b. Scaling up the Tcw with a mathematical non-linear function revealed a good correlation between the scaled Tcw and the Tm, after 1,000 s, approximately 16 minutes, of the process initiation. This positive study result led the team to investigate whether more advanced AI methods could be used to estimate melt temperature non-invasively.

Subsequently, a deep neural network (DNN) model was developed in Python to relate the cooling water temperature to the melt temperature →04a. The DNN model, trained on historical data, could predict the melt temperature from the cooling water temperature rise with an acceptable accuracy →04b. With further modifications to the analysis and improvements in data collection, better accuracy prediction is expected in subsequent investigations. Currently, ABB is working to be able to integrate the non-invasive

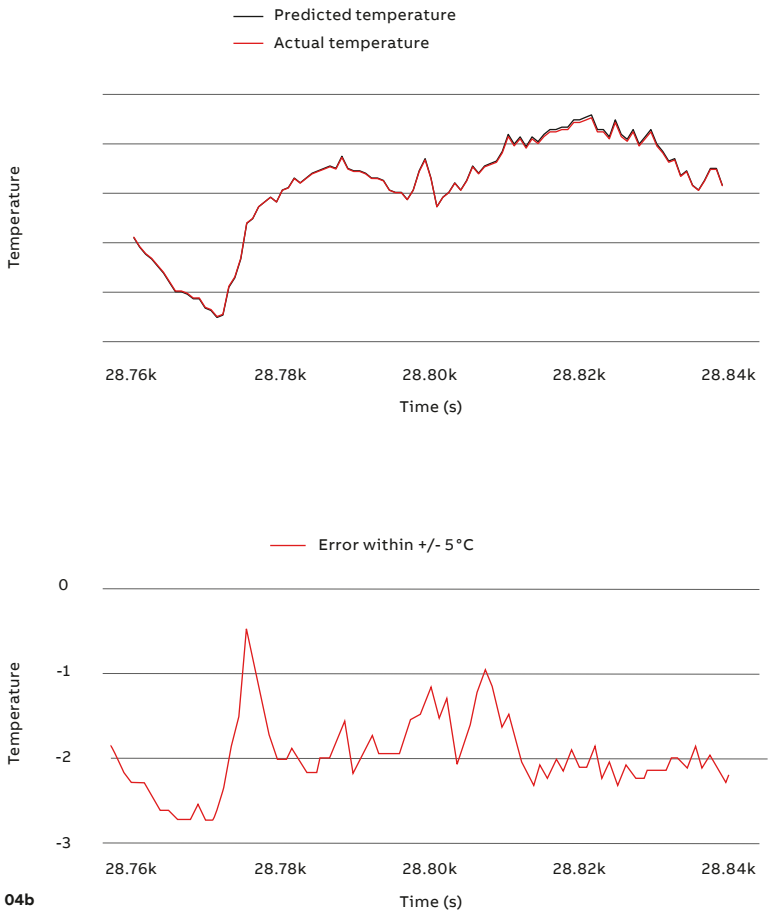
—
04 The NN model results are presented.

04a A simplified neural network schematic relates cooling water temperature to melt temperature.

04b Predicted melt temperature closely agrees with actual temperature (upper graphic) and the low associated error values (lower graphic). The temperature axis units have been omitted for proprietary reasons.



04a



04b

temperature estimation code in its control platform as an offering for metal processing operations.

Unique advantages

In this study, ABB has shown that it is possible to satisfactorily predict process behavior non-invasively, eg, melt temperature, using AI modeling methods as long as relevant process conditions are known, the availability and quality of data is sufficient and domain experts are involved. In ABB's case, the technologist will be able to non-invasively estimate internal parameters. This capability is not only gratifying, it also has extensive practical implications: Non-invasive melt temperature estimation will allow real-time temperature monitoring. This in turn provides

—

ABB's AI model allows the steel melt temperature to be predicted continuously from the cooling water temperature rise.

an invaluable means to optimize the operational process: The melting process continues while the need to shut down the electrode power, even momentarily, and to discard electrodes, is obviated, thereby saving time, energy and costs. Importantly, the ability to monitor temperature in real-time allows for the control of off-gas emissions; this is a significant concern for the steel making industry not only in terms of operational efficiency but is also imperative for the industry's efforts to reduce GHG emissions to address customer, investor and regulatory demands.

Outlook

While the primary idea of this targeted investigation was to examine whether cooling water temperature could be be used as a proxy to predict melt temperature, ABB proposes, based on the positive results to date, that other external measurements, such as the off-gas temperature, could be used to estimate the melt temperature using advanced DNN methodology. Such investigations are underway. In this way, ABB, with its strong focus on metals and digital technologies, is working to create value for the steelmaking industry through analytics-based innovations. •

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Further information

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ABB website, "Enduring electric arc furnace optimization technology plays a part in steel's sustainable future"

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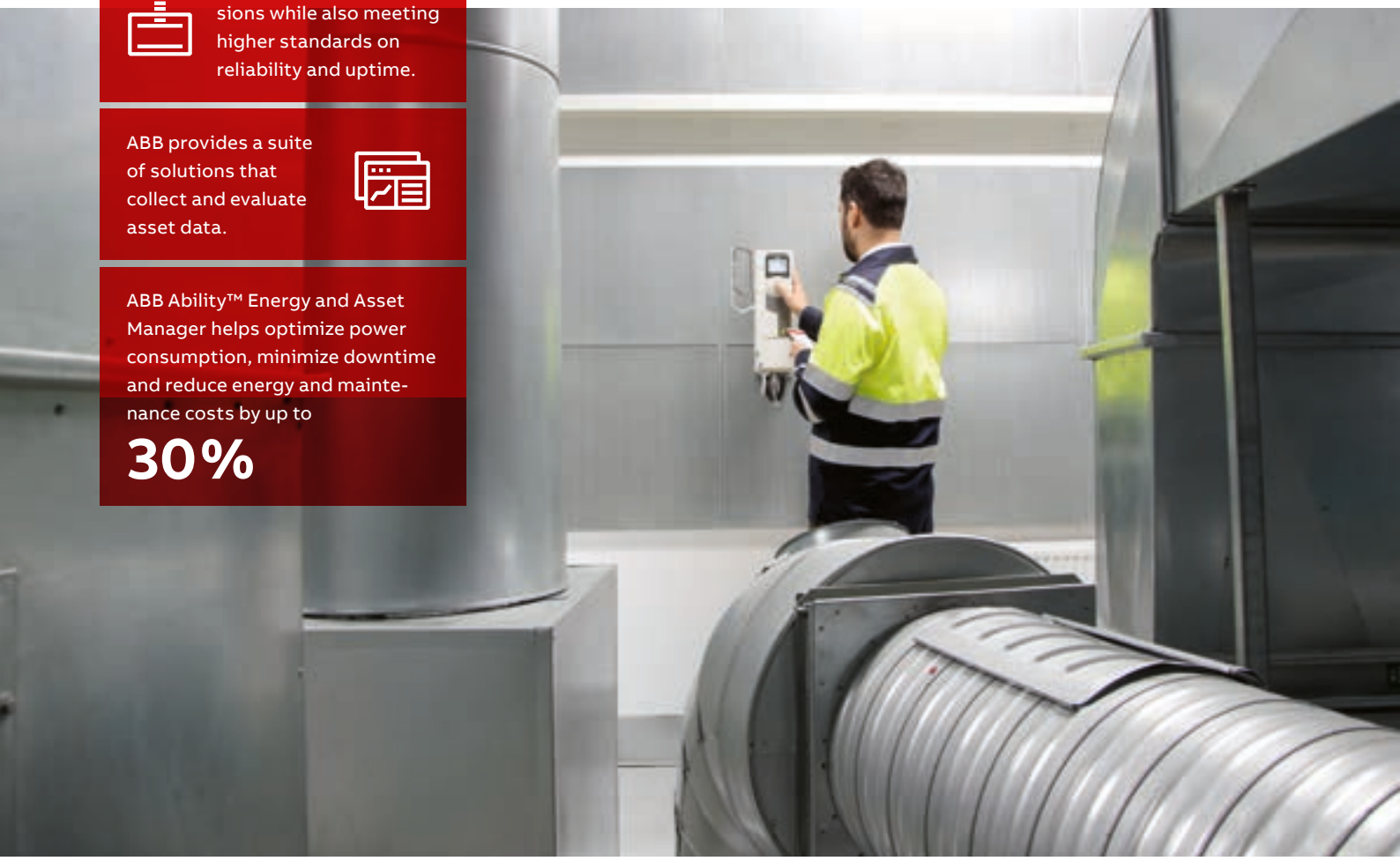
Companies are under pressure to reduce emissions while also meeting higher standards on reliability and uptime.

ABB provides a suite of solutions that collect and evaluate asset data.

ABB Ability™ Energy and Asset Manager helps optimize power consumption, minimize downtime and reduce energy and maintenance costs by up to

30%



HELPING CUSTOMERS ACCELERATE THE JOURNEY TO NET ZERO

Granular visibility

ABB Ability™ Energy and Asset Manager helps users optimize power consumption, minimize downtime and reduce energy and maintenance costs by up to 30 percent. To a large extent, this is accomplished by segmenting, monitoring and data analysis down to individual pieces of equipment and subsystems, such as an elevator or a single HVAC system. The common denominator of this granular approach is that users are able to access a full picture of their connected assets' health.

01

— 01 ABB Ability™ Energy and Asset Manager provides intuitive dashboards.

Energy plays a vital role in keeping every business running. Managing the cost, safety, and efficiency of that energy – including electricity and other power sources – is paramount to controlling operating expenses and reducing the risk of costly downtime or even catastrophic failure. The average cost of unplanned equipment downtime in manufacturing is $260,000 per hour [1], making energy and asset management a business imperative.

Government deadlines for reducing emissions are also drawing ever closer. To keep global warming to no more than 1.5°C – as called for in the Paris Agreement – emissions need to be reduced by 45 percent in the next seven years and reach net zero by 2050. However, at present, the average building wastes an estimated 30 percent [2] of the energy it consumes due to inefficiencies, resulting in unnecessary – yet easily avoidable – carbon emissions.

— Businesses can track specific performance trends by configuring parameters, devices, operations and time periods.

As energy prices rise, infrastructure ages and government restrictions on carbon emissions proliferate, businesses are turning to digital solutions that will help them maintain uptime, get the most out of their assets, remain compliant, and accelerate their journey to carbon neutrality. ABB Ability™ Energy and Asset Manager, a modular, state-of-the-art cloud-based system providing intuitive dashboards →01, offers a solution.

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Ratingen, Germany

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With real-time visibility into energy consumption, electrical power quality, and the health of low- and medium-voltage electrical distribution system equipment, the solution helps organizations with multiple small or medium-size sites – such as factories, commercial buildings, and data centers – optimize power consumption and minimize downtime.

The digital solution's modules can be purchased separately or together. Monitoring can also be segmented down to individual pieces of equipment and/or sub-systems, such as an elevator, a single HVAC system, or a production line. This enables users to make informed decisions regarding when to reduce energy consumption, how to avoid unplanned downtime and how to use predictive maintenance to detect and proactively address issues before they escalate.

ABB Ability™ Energy Manager
ABB Ability™ Energy Manager adds value to users' facilities and sites by supervising electrical systems and providing clear information about consumption that makes cutting waste and improving energy efficiency simple.

As every facility has different energy needs and targets, ABB Ability™ Energy Manager uses configurable widgets to meet the needs of each organization. Businesses can monitor their energy consumption across a select period and compare different groups' energy consumption across multiple sites. They can also track specific performance trends by configuring the parameters, devices, operation and time period.

Reports are fully configurable to customers' needs and can be received remotely via email. The system also offers automated alerts, allowing customers to receive immediate feedback on the status of their sites 24/7. Altogether, the features included in ABB Ability™ Energy Manager offer sustainability, operational and performance benefits.

One of the many advantages of this solution is that, for example, by identifying hidden energy drains and eliminating waste, customers can achieve up to a 30 percent increase in efficiency. Facilities also benefit from lower energy bills and reductions in unplanned downtime. Furthermore, Energy Manager is easy to commission and install, and is scalable, from a single site to a multi-facility system.

ABB Ability™ Asset Manager
In a similar way, ABB Ability™ Asset Manager provides analysis of device data across customers'

VIKING ANALYTICS

Viking Analytics' [4] vision is to enable every industrial service company, including maintenance companies, OEMs, and system integrators, to monitor more machines reliably. Viking Analytics' proprietary solution prioritizes the machines that need attention, while providing relevant explanations for the prioritization. Experts can then provide feedback based on the priority list and recommend actions, which are learned by the solution. With the Viking Analytics solution, service companies can offer reliable remote monitoring services with fewer false alarms and without in-house AI teams.

02

TALLARNA

Tallarna [5] is an award-winning climate tech company for the built environment. By combining data analytics, performance guarantees, and efficient funding, the company makes decarbonization projects executable at speed and scale. Tallarna works with large residential and commercial landlords, energy infrastructure developers, and technology providers to accelerate net zero. Tallarna was recently named one of 'The 20 Hottest Startups in AI' by PwC and the University of Cambridge.

03

facilities that delivers granular visibility of the behavior of their electrical assets in real-time, in both low-voltage and medium-voltage environments. By monitoring asset condition, performance trends and alarm states, it enables condition-based and predictive maintenance that significantly reduces downtime and operational costs.

The system can also be tailored to each customer and site. The common denominator is that each user will be able to access a full picture of their connected assets' health with clear categorizations for appropriate action, from "very poor" (mostly failed, urgent action required) to "very good" (running well, no action needed). This can be distilled into a wide range of reports, allowing businesses to gain a better understanding of how their assets are performing and identify key trends.

By implementing this system, customers can save up to 40 percent of maintenance costs and eliminate up to 30 percent of maintenance-related site intervention [3]. By digitizing electrical assets and optimizing maintenance cycles, they can also increase asset lifespan and reduce their environmental impact. In fact, 50 percent of electrical equipment such as metal cabinets, steel plates and busbars – products with high carbon footprints – can be used perpetually without being replaced if components such as circuit breakers are regularly monitored, maintained and upgraded.

Electrical infrastructure, including switchgear, can be digitized rapidly with plug-and-play kits.

The best news is that electrical infrastructure, including switchgear and other equipment, can be digitized rapidly with plug-and-play kits, allowing customers to connect to the cloud and use ABB Ability™ Asset Manager quickly. Like Energy Manager, the system can also be easily scaled to multiple sites.

Scalable solutions

ABB Ability™ Energy and Asset Manager's applications are designed to be an ever-growing ecosystem to which new solutions can be added. By using Application Programming Interfaces (APIs), the system's capabilities can be extended as rapidly as technology develops. A key example of this is ABB's partnership with Viking Analytics, a Swedish startup that won ABB Electrification's Startup Challenge in 2020 →02. Here, ABB Ability™ Asset Manager will be integrated with Viking Analytics' advanced AI-powered analytics engine to automatically detect unseen or pre-failure operational conditions for electrical equipment.

The AI engine operates in coordination with ABB Ability™ Asset Manager, adding advanced analytics that support businesses' ability to predict and prevent faults in their electrical equipment in an

— 02 Viking Analytics.

— 03 Tallarna.

04 OKTO GRID.

even more granular way than before. This makes it easier for them to prevent costly failures, plan maintenance efficiently and maximize uptime.

On the ABB Ability™ Energy Manager side, one of ABB's most successful integrations to date has been with Tallarna →03, a UK-based climate tech startup that has created an innovative approach to decarbonization projects for large property portfolios and energy infrastructures. Using AI-powered data analytics, customers can view the viability of energy optimization solutions alongside the availability of performance insurance and third-party finance on a single platform.

The above examples illustrate that ABB's quest for customer value is not limited to its in-house development capabilities but is based on a commitment to partnering with startups that can contribute to ABB's offer by commercializing their innovations on the ABB Ability™ marketplace.

Constant evolution

As the energy landscape continues to evolve, so too will the solutions offered by ABB Ability™ Energy and Asset Manager, which are constantly being refined, not only via the integration of new applications, but also through ABB's focus on enhancing back-end infrastructures.

In terms of application development, ABB has exciting plans to introduce additional features, particularly regarding its asset management capabilities, such as end-to-end asset management solutions for a complete substation, encompassing medium-voltage, low-voltage and transformers – a frequent customer request. To address increasing demand in this area, ABB

ABB is partnering with several startups, enabling customers to conduct their own audits.

is working with OKTO GRID →04, a company specialized in transformer monitoring solutions. OKTO GRID's unique sensor technology is non-invasive, where a monitoring device simply attaches magnetically to the transformer surface. Data is transmitted to the cloud almost instantaneously. This partnership allows ABB to offer a comprehensive transformer monitoring solution to the market.

In the realm of energy management, ABB is partnering with several startups to enrich its energy analysis and optimization features, thus enabling customers to conduct audits based on predefined standards.

The world of asset and energy management is evolving rapidly and those businesses that do not plan to digitize their physical infrastructure in the coming years will be finding it more and more challenging to keep up with competitors that instead choose to do so. ABB customers are in no danger of that. Not only will ABB continue to develop its digital solutions, but its strategic focus on partnering with innovative startups will ensure that ABB and its customers will always have access to cutting edge solutions capable of reaching new levels of operational and energy efficiency. •

OKTO GRID

OKTO GRID [6] is on a mission to digitize transformers to handle new energy sources and rising energy consumption. The startup's non-invasive sensing technology allows electricity providers to add a digital interface to any transformer in less than ten minutes with no tooling needed. By gaining access to transformer performance data, grid professionals can monitor, forecast, and react to congestion and reduce the cost of asset management.

Bringing transformers online for the Energy Transition.

04

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Cavitation

Several of the articles in this edition of ABB Review relating to ABB Dynafin™ mention cavitation and stress its importance in marine design. But what exactly is cavitation and why can it be detrimental to marine systems?

Anthony Byatt
External contributor

In the realm of fluid dynamics, cavitation is a phenomenon characterized by the formation and implosion of vapor bubbles in a liquid when the local pressure falls below the vapor pressure. This process occurs when a liquid, such as water, experiences a rapid change in pressure, typically in regions of high-velocity or low-pressure gradients. The formation and collapse of these bubbles create intense shock waves that can have significant detrimental effects on ships, particularly on their propellers.

In marine propellers, the bubbles are formed by the creation of low-pressure regions at the back of the blades as they move through the water at high velocity.

Breaking and shaking

Most marine propellers are actually designed to allow cavitation, as it is then possible to reach higher efficiency. Cavitation must, in such cases, appear as a stable sheet, rolling smoothly over the tip of the blade. When cavitation is unstable, erosion can occur: When vapor bubbles collapse near the surface of the propeller blades, they release energy in the form of small, high-velocity jets. These jets can impinge on the material surface with a significant force, causing pitting and erosion. Over time, these effects can degrade the integrity of the propeller blades, leading to reduced performance and increased maintenance costs for vessel operators.

Furthermore, cavitation-induced vibrations can also degrade the structural integrity of the propeller and the rest of the propulsion system. The pressure pulses created by the collapsing vapor bubbles propagate through the surrounding fluid, inducing vibrations in the propeller blades and other components of the propulsion system, leading to fatigue and potential failure over time. In addition to the pressure pulses, the noise generated by cavitation can also be a concern in terms of its impact on marine life in sensitive areas and on the comfort and safety of the vessel's crew and passengers.

Cavitation mitigation

Engineers employ various materials and design techniques to mitigate the adverse effects of cavitation on propellers. Propeller designs may feature modified blade profiles or cavitation-resistant materials to reduce the likelihood of cavitation and minimize its effects when it does occur. The computational fluid dynamics (CFD) simulations described elsewhere in this

Cavitation-induced vibrations can degrade the structural integrity of the propeller and the rest of the propulsion system.

Title photo: ©Denys Yelmanov/stock.adobe.com

Buzzword Demystifier

edition of ABB Review are a good example of how engineers analyze and optimize propeller designs to minimize cavitation-induced performance losses.

Cavitation is a complex fluid dynamic effect with significant implications for ship propulsion systems. While cavitation can enhance propulsive efficiency under certain conditions, its effects are mostly adverse, in the form of erosion, vibrations and noise, leading to performance and integrity degradation over time. The

ABB used advanced design techniques to mitigate cavitation and optimize Dynafin's performance and longevity.

ABB Dynafin team has invested much time and effort in understanding fully the mechanisms of cavitation and its effects. The knowledge gained informed the advanced design techniques and technologies they used to ensure the optimal performance and longevity of the ABB Dynafin propulsor. •

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