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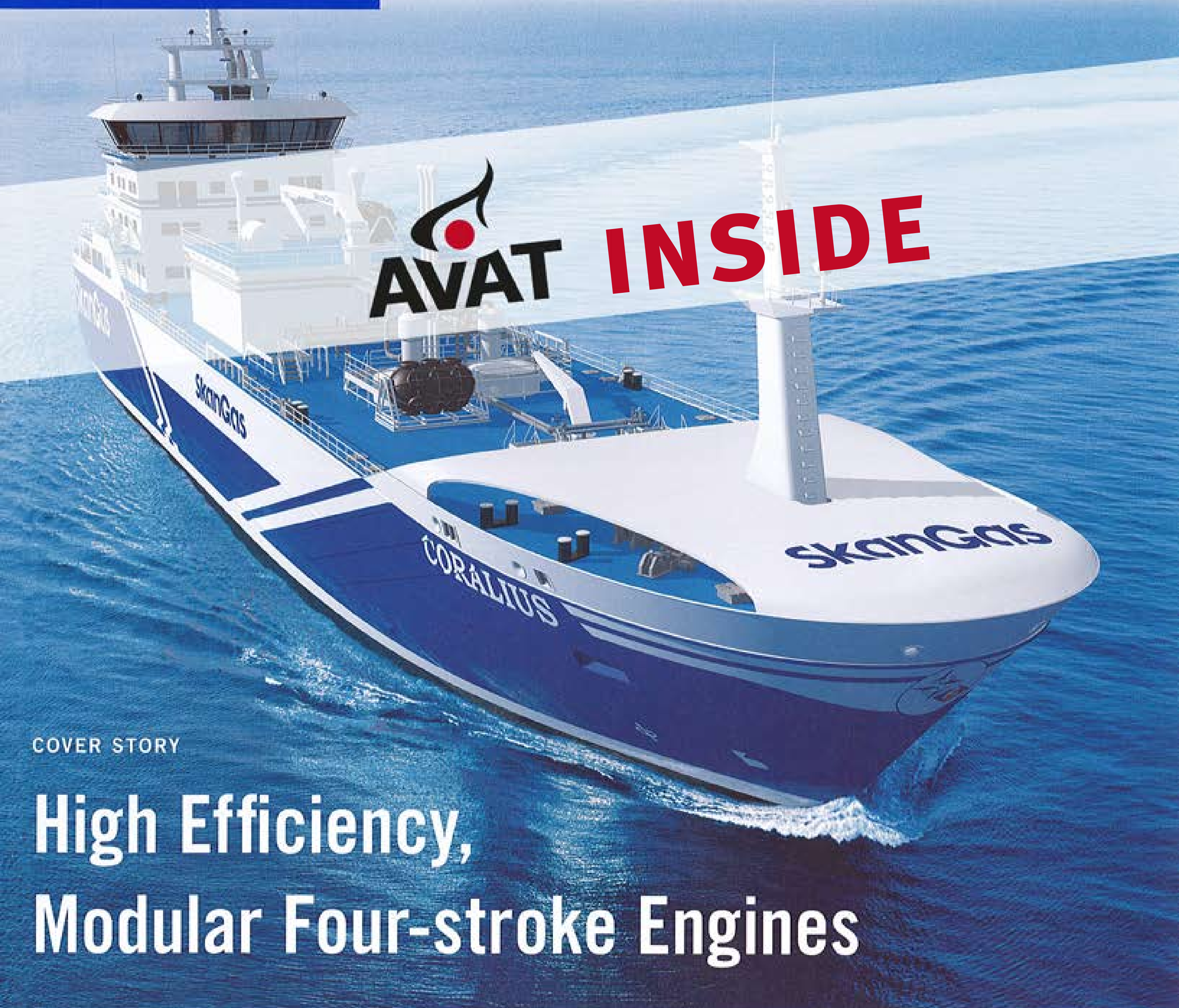

AVAT INSIDE

COVER STORY

High Efficiency, Modular Four-stroke Engines

OFFICIAL MAGAZINE OF CIMAC
INTERNATIONAL COUNCIL ON COMBUSTION ENGINES

SIMPLIFIED INJECTION SYSTEMS for Dual-fuel Engines

DIESEL TO DUAL-FUEL RETROFIT on Container-feeder Ship

/// **GUEST COMMENTARY** Günther Gern [WTZ] /// **INTERVIEW** Michael Schmitt [STW]

Engine Control with Open Software Based on an Industrial PLC

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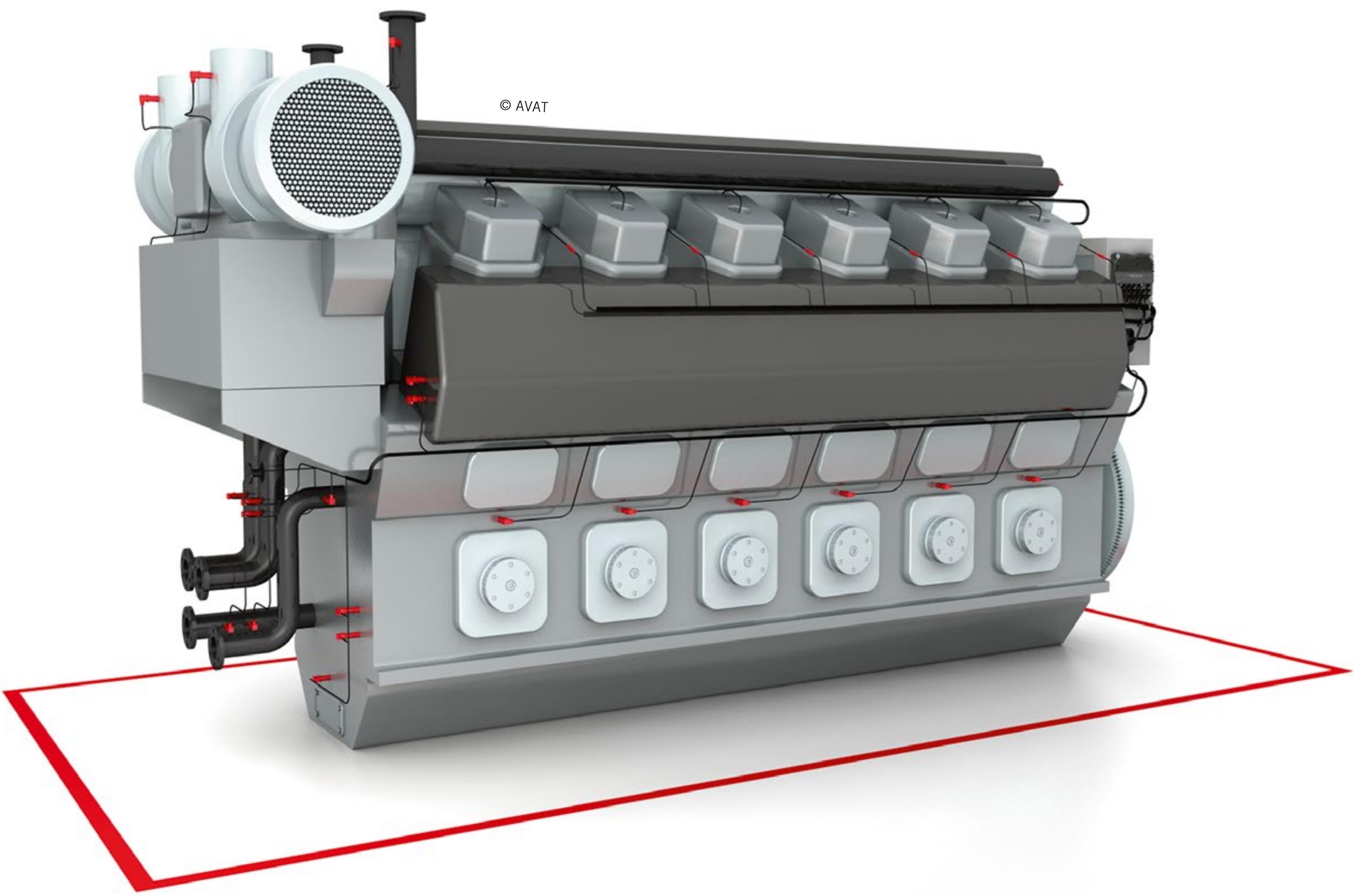
The role of control systems as a product differentiator and enabler of new functions has led AVAT Automation to restructure its offering from customer-specific gas engine controllers to control platforms with open software based on industrial PLCs. The openECS concept allows the engine builder maximum scope to further develop products from their own resources and software competencies.



MOTIVATION

The growing importance of software in terms of engine characteristics has led engine builders to acquire their own software developers to fulfil new requirements for engine flexibility and performance. This demands cooperation models which allow engine builders to rapidly leverage new technologies and relieve the pressure on their development teams while still allowing control over major software elements.

In response, AVAT Automation has developed the openECS engine control platform, employing an industry standard programmable logic controller (PLC) and open software, supplemented by AVAT special-purpose modules for engine and application specific functions.

THE SMART ENGINE

Based on future customer expectations and trends, large engines should be developed to "smart engines", opening new possibilities for their optimisation while also increasing the complexity of their systems. Trends such as the "Internet of Things" (IoT), "Industrie 4.0" or "Smart Manufacturing" point the way in which products will be developed.

In general, smart products are distinguished by the following [1]:

- They are interlinked with other systems.
- They adapt themselves automatically to their operating conditions.
- They are tailored to customer needs.
- They collect information about their application, which are aggregated and evaluated at a central server.
- They are constantly optimised in terms of performance, efficiency and availability.
- They are sold in combination with services (Product-as-Service, Pay-per-use).

NETWORKS

All these characteristics can be used in the operation of combustion engines. In power generation, generator sets are no longer solely controlled by local supervisory control and data acquisition (SCADA) systems but are components of large-scale "virtual power stations" and play a role in energy trading and grid stabilising. In mobile or marine hybrid applications they are integrated with batteries and electric motors into virtual machines. In this way systems are created with interesting dynamic characteristics or new revenue models. The precondition for this coupling is flexible data interfaces.

ADAPTATION

On the gaseous fuel side new energy sources such as pyrolysis gases, shale gases, biogases and hydrogen are coming on stream and there is great interest in feeding them into the natural gas supply system, in order to spatially separate gas and electricity production and to use the high storage capacity of the gas network. For gas engines this means having to automatically adapt to unknown gas compositions and higher temporal variations in fuel combustion characteristics.

PRODUCT VARIANTS

Customers demand products which are specifically tailored to their applications, users, and country-specific requirements. This is particularly true in times of buyers' markets and can only be attained at economic cost via modularisation. Ideally, the variants should only differ in their software.

DATA ACQUISITION

Engine builders and plant operators acquire far too few data. Automatic feedback on usage and failures is opening new paths to product optimisation. In combination with other information it enables optimised deployment of resources (maintenance, consumables) and new invoicing methods based on expected wear. In other industry sectors usage data have created new costing models and provided incentives to further develop products in terms of diagnostic capabilities, durability and service-friendliness.

CENTRALISED DATA MINING

Complex functions which rely on experience data, like condition monitoring and automatic diagnostic systems are relocated from the engine controller to a central server. The data compiled are the basis for further development of the algorithms. This is achieved by means of software and hardware modules which gather data on the engine controller, pre-process them and transfer them to the server for evaluation.

CUSTOMER EXPECTATIONS

Users of a smart product expect it also to be state-of-the-art in its ease-of-operation and safety. A precondition of internet communication is protection against unauthorised access and a precondition for customers to allow automatic data acquisition is transparent and professional data protection, because essentially this is a fair exchange of "data versus added value". Finally, users are coming to expect the ease of operation of a smartphone or a tablet on industrial devices.

COMPLEXITY

Trends show that in future the complexity of Engine Control Systems (ECS) will increase significantly. As well as the core task of engine control and monitoring additional functions and short development cycles are needed.

INDUSTRIAL PLCS

In the reorientation of the AVAT product portfolio to meet these new needs a key task was to develop a platform that covers all functions relevant to engine builders and plant engineers. AVAT already has specific devices which communicate the functions via various data interfaces and the aim was to distribute customer development tasks over as few devices as possible to minimise development tool maintenance needs.

The flexibility and interoperability of industrial PLCs make them ideally suited to SCADA systems and auxiliary control. Their modularity makes them flexible to configure and they support numerous standard data exchange interfaces. They are thus ideal for system integration. Using specialised modules PLCs encompass many applications which previously required dedicated devices, such as motion control, robotics or safety functions.

PLCs also represent professional development tools made for engineers needing to perform technical tasks. Configuration tools, editors, compilers and debuggers are often already integrated into a development environment. Today most PLCs are programmed

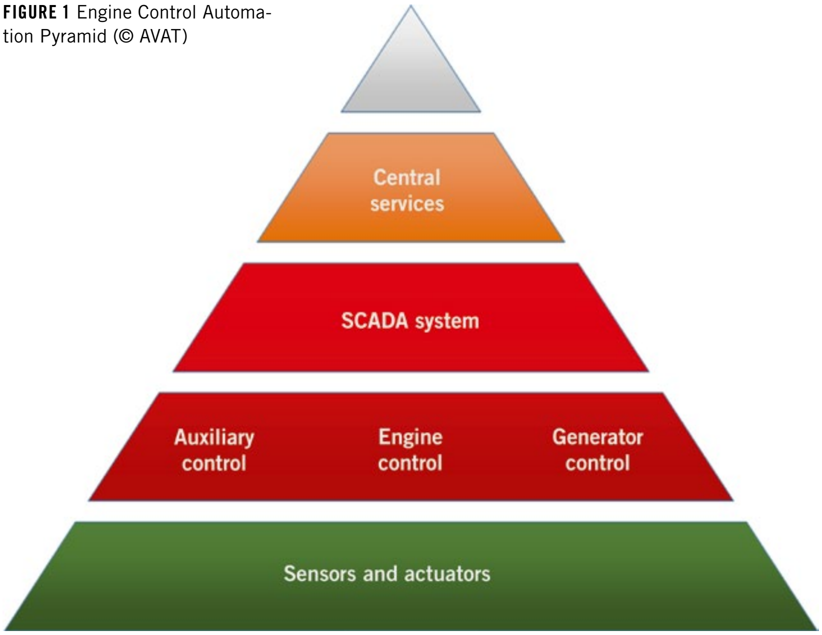


FIGURE 1 Engine Control Automation Pyramid (© AVAT)

according to the IEC 61131-3 standard and many manufacturers have joined the PLCopen organisation. This pan-manufacturer standard offers great advantages in terms of staff recruitment and ensures the portability of the solution.

For long-term availability, the separation of input/output (I/O) modules and CPU modules allow a number of manufacturers to offer spare parts security over many years and, at the same time, further development of performance via new CPU modules.

For these reasons AVAT has adopted modular industrial PLCs for the functions auxiliary, generator and motor. The SCADA level can also be implemented using modules from the same PLC family, so that the whole plant can be automated using a uniform platform, as shown in the Automation Pyramid in **FIGURE 1**.

Specifically, AVAT selected the M1 system manufactured by Bachmann electronic GmbH based on:

- compactness, since the space for control cabinets is always limited around the engine
- robustness to allow installation directly on the engine
- marine type approvals for all components
- favourable Matlab/Simulink connectivity for rapid prototyping processes.

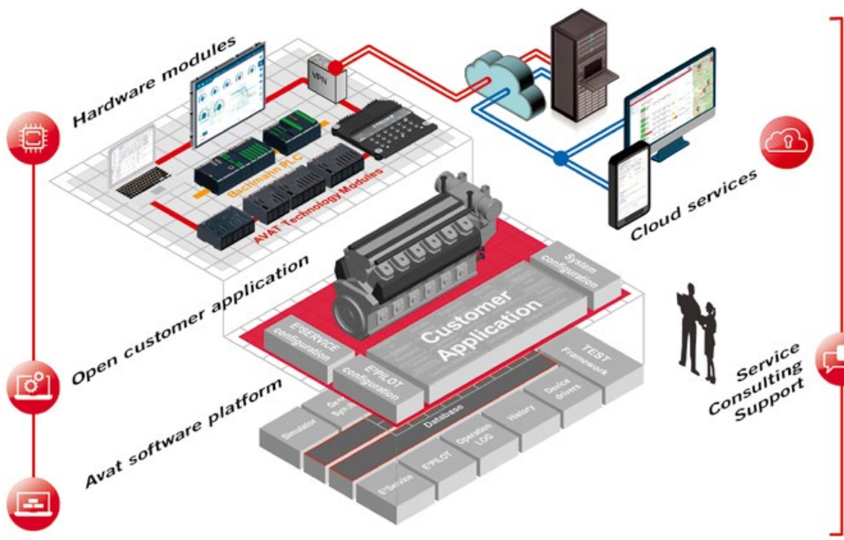


FIGURE 2 The modular AVAT openECS platform comprises 4 technical layers and supporting services (© AVAT)

GAPS BETWEEN PLC AND ECS

Modular PLCs are ideal for auxiliary and SCADA tasks, bus as engine controllers they lack important functions. In a strategic partnership between AVAT Automation and Bachmann electronic, these gaps have been closed to create the openECS engine control platform.

In terms of engine specific I/O, several sensors and actuators commonly used on engines are not directly connectable to standard PLCs and special solutions were employed. AVAT signal processing modules use standard I/O to implement special functions such as speed measurements from typical gear tooth patterns. Special actuators or sensors are connected to expansion modules and comprehensively integrated into the PLC by means of software building blocks. Special sensor signal processing takes place in the expansion module itself, in order to reduce the workload on the PLC. Additional devices, like ignition systems, are integrated by means of specific AVAT communication drivers. In terms of the Automation Pyramid, **FIGURE 1**, special functions are thus transferred to the sensor level.

So as not to limit the potentials of the openECS regarding control strategies, the modules all operate as “smart sensors” or “smart actuators”. They deliver processed information but assume no control functions, significantly improving system testability and risk assessment (FMEA).

DIAGNOSTICS

As demanding technical systems, accurate diagnosis of wear or defects on gas engines is not trivial and requires experts with access to large data quantities. Standard trending and event logging solutions already integrated into PLCs are insufficient for experts in terms of data volume, detail, temporal resolution, depth of storage and handling. As a result the AVAT diagnostic suite was embedded into the openECS system.

FIGURE 3 The heart of the openECS control system are Bachmann PLC Series M1 PLCs with a range of CPU powers (© AVAT)

TOOLBOX

Using these hardware modules and the proven AVAT ECS software, a comprehensive tool box of hardware, software and services was assembled for the development of engine controllers. The prime challenge was implementation of uncompromising modularisation so that system elements can be inserted independently of each other. The overriding consideration was the desire to create a thoroughly, perfectly integrated system, as shown in **FIGURE 2**.

The hardware modules at the heart of the system are the Bachmann PLC Series M1, **FIGURE 3**, with a range of CPU powers, flexible communication modules and comprehensive I/O modules for all types of digital or analogue signals. For simplified spare parts inventories, AVAT recommends customers to concentrate on a limited number of different modules.

With the M1 Series different levels of redundancy and a spatial distribution of the I/O modules in the plant can be implemented. Using the GSP, GSM and GM modules, synchronisation and generator/grid monitoring can be realised directly in the system. All measured quantities are available both for the prescribed safety functions and for all other forms of control.

TECHNOLOGY MODULES

Complementing the M1 PLC with the special functions typically required by engines are AVAT's established combustion control modules E^2KNOCKCON, a structure-borne sound processor for knock and misfire detection and E^2PRECON for cylinder pressure analysis. Both modules are now available in very compact packages. For its part, AVAT's E^2CORE offers a flexible actuator module for the control of throttle valves, waste-gates and gas mixers. **FIGURE 4** shows the standard version of E^2KNOCKCON and **FIGURE 5** the redesigned openECS module. The E^2PRECON devices follow the same redesign pattern.

AVAT modules use the same form factor as the M1 and occupy a minimum of space in the control cabinet. All modules are connected to the PLC via CAN and can thus also be used with other engine controllers or PLCs. In this case, E^2CORE can autonomously control engine speed, power and air/fuel mixing in order to reduce timing and performance requirements on the PLC.

Like the Bachmann modules, the AVAT modules withstand elevated temperatures and vibrations and can be installed in panels directly on-engine. In addition, most of the modules are Classification Society certified for marine applications.

FIGURE 4 AVAT's E^2KNOCKCON structure-borne sound processor for knock and misfire detection is integral to openECS – seen here is the "M" suffix marine version with Classification Society approval (© AVAT)

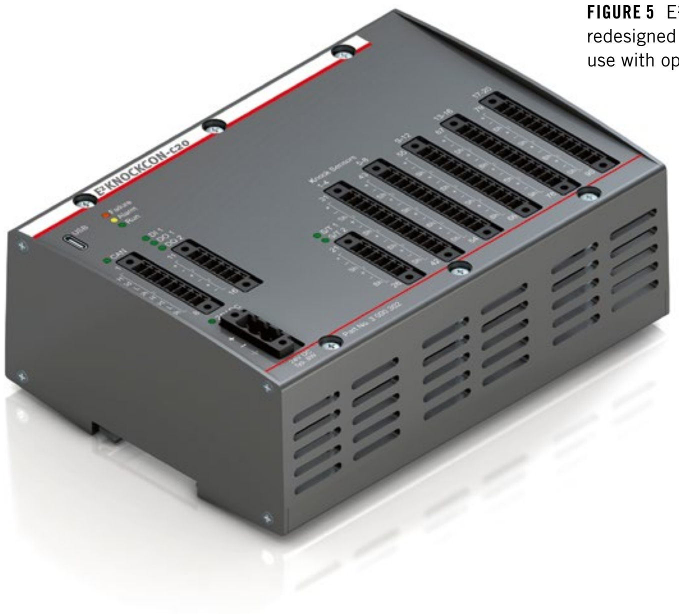


FIGURE 5 E²KNOCKCON in its redesigned modular version for use with openECS (© AVAT)

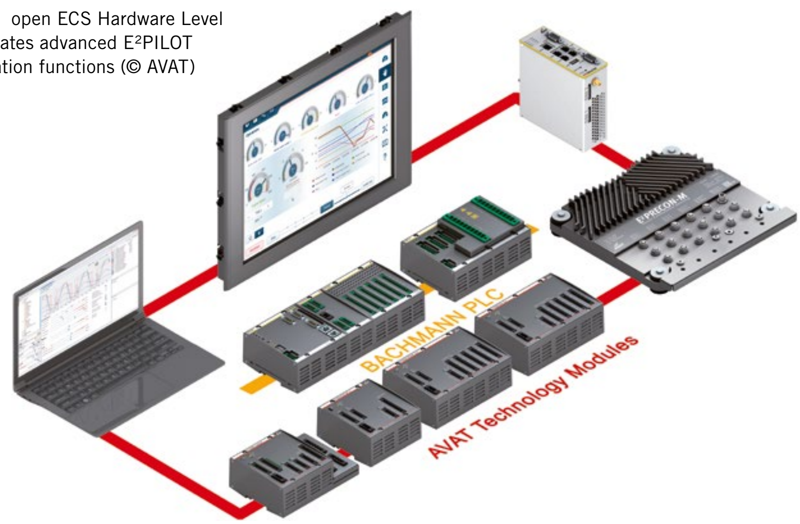


FIGURE 6 open ECS Hardware Level incorporates advanced E²PILOT visualisation functions (© AVAT)

VISUALISATION

The system offers possibilities in addition to connection of third party visualisation via data interfaces. AVAT's E²PILOT visualisation package for multi-touch user interfaces is specially tailored to plant operators' needs and is contained in Hardware Level 1 of openECS, **FIGURE 6**. When scrolling, the interactive operation log or the configurable trends offer the comfort smartphone users are used to. Customer-specific engine visualisation requires only a few lines of configuration code. A specifically configured E²PILOT screen is shown in **FIGURE 7**.

AVAT's E²SERVICE, on the other hand, is a tool for ambitious service technicians with displays configured for maximum time-saving during typical tasks such as commissioning, controller adjustment, fault finding and maintenance. The operation log includes context information, filter, jump and search functions. Parameters include an inline help function as well as save, restore and compare features. A typical E²SERVICE screen is shown in **FIGURE 8**.

OPEN CUSTOMER APPLICATION

The open customer application layer contains all the controllers, sequences and functions that control and monitor the behaviour of the engine or its periphery. Everything specific to a given engine or a customer is configured and programmed here. As illustrated in **FIGURE 10**, the engine builder or plant engineer receives unrestricted access to the source codes of this layer and can thus see and change details himself. The Bachmann M1 solution centre makes available a powerful development environment featuring several programming languages according to IEC 61131-3, thus offering all the features of a modern PLC. In addition it is possible both to incorporate code generated automatically by Matlab/Simulink and to test it interactively.

A special feature of openECS is the central application database, where the characteristics of all important data objects are configured so that all monitoring, logging and recording functions run on the platform in the background. Since the configuration can be changed dynamically in the program, variable limits or complex enabling conditions are feasible. In this way uniform functionality and straightforward testability are achieved. Additionally, parts of the documentation can be automatically created from the configuration data, like lists of parameters and limit values or data point lists for external interfaces.

AVAT SOFTWARE PLATFORM

This is the backbone of the system. As shown in **FIGURE 9** for openECS Level 3, it contains, among other things:
– development and testing tools
– libraries of engine-typical functions (e.g. balancers, speed/load/mixture controls)
– the database with all data objects
– the diagnosis suite consisting of operation logs, history recording and the appropriate user interfaces
– specific device drivers, e.g. for AVAT technology modules or 3rd party units such as ignition systems
– a built-in simulation framework.

As shown in **FIGURE 10**, the platform makes tools and building blocks available which significantly accelerate application development. In addition, by using tested software modules, further testing can be minimised.

REMOTE INFRASTRUCTURE

For direct remote access to the controllers, pre-configured VPN routers are offered which create a secure communication tunnel from the plant to a secure rendez-

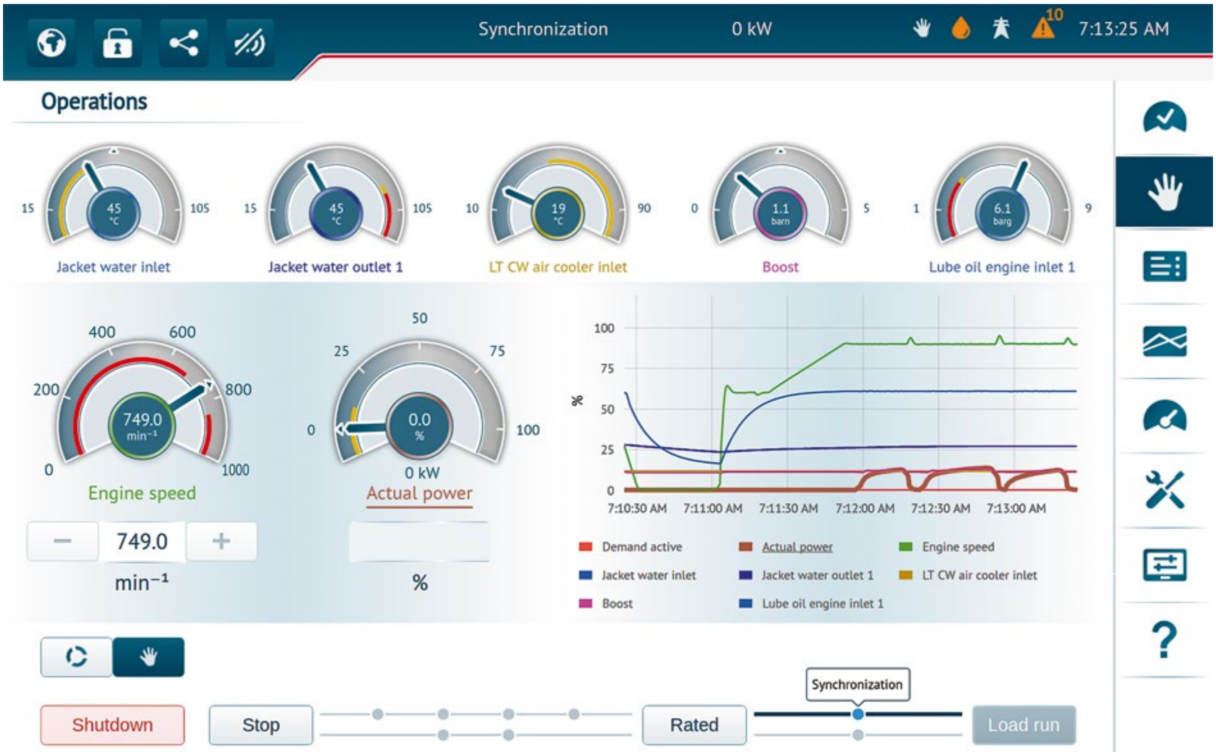


FIGURE 7 E²PILOT is a convenient multi-touch user interface for plant operators including trends, operation logs and test functions (© AVAT)

vous server. Authorised service staff can log into the server and dial into the plant.

Of greater interest for the future is data collection at the central server. The platform software modules take over the time-controlled or event-triggered transmission of encrypted data packets via the Ethernet to the central server where data is processed further. Currently modules are offered for status notification and forwarding of alarms while maintenance planning and condition-

FIGURE 8 The E²SERVICE tool for ambitious service engineers presents copious, well-structured detail (© AVAT)

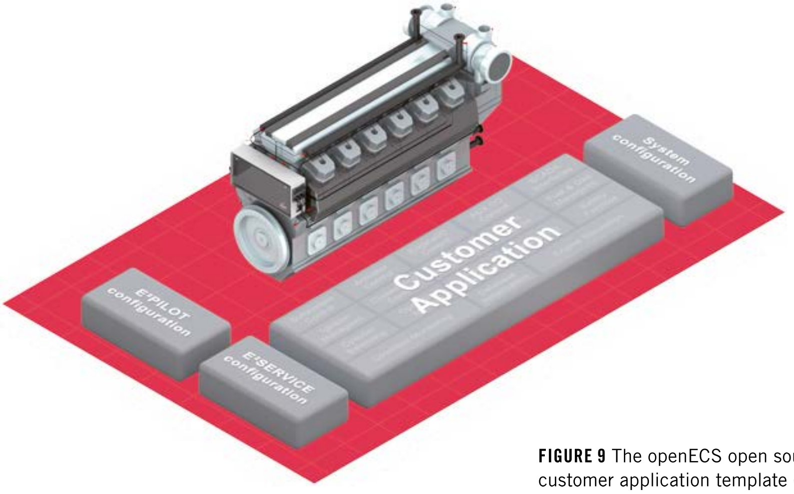


FIGURE 9 The openECS open source-code customer application template (© AVAT)

based monitoring are in preparation. Comprehensive management of access rights enables multi-client capability with selective user-specific rights.

THIRD PARTY CONTRIBUTIONS

The future-proof aspect of a system is strongly dependent on how well it functions with products from other manufacturers. At the hardware level the modules communicate using open communication standards based on CAN or Ethernet (except for M1 modules among themselves). Driver building blocks are included in the platform for commonly used third party devices. At the application level almost any software module can be integrated. The development tools are equipped with interfaces for integrating external tools for source code management, ticketing or test frameworks.

SIMULATION

Situations may arise where an engine cannot be run at relevant operating points but must nonetheless complete a formal release process before the developed product can be used by the customer. Simulation relieves these bottlenecks and brings significant savings. While hardware-in-the-Loop (HiL) simulators are certainly important for verifying the overall system, for many purposes they are unwieldy and overdimensioned. Internal simulators integrated directly into the system by AVAT are now indispensable to daily tasks in development, tuition, testing, documentation and sales.

CONTROLLER EXAMPLES

A typical controller configuration for a customer application is shown in

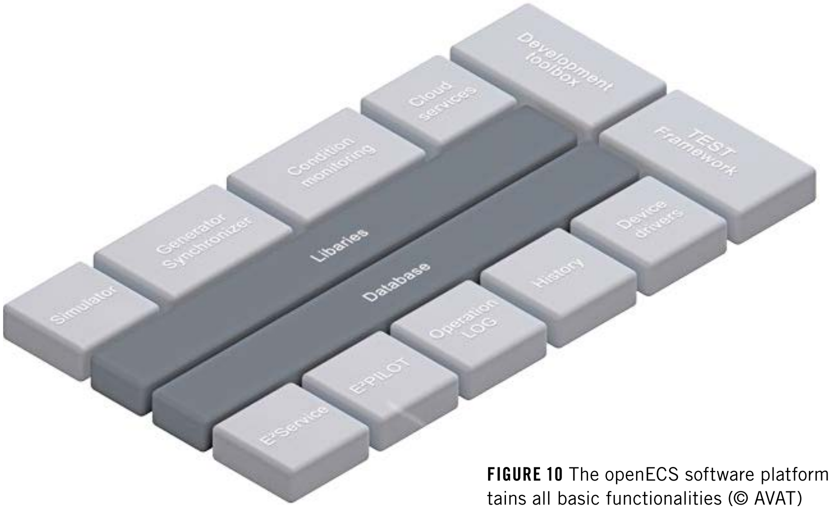


FIGURE 10 The openECS software platform contains all basic functionalities (© AVAT)

FIGURE 10. As mentioned above, in this example internal simulators are integrated.

Two examples demonstrate very different engine controllers created using the openECS toolbox. Both are operated using the E²PILOT user interface and the data of all components are usable for control and monitoring purposes and can be represented via the E²SERVICE service tool.

In the 300 to 500 kW class, an openECS was designed for a typical mixture-charged lean-burn stationary gas engine with mixer, throttle and wastegate. The installation space requirement for the PLC components (HxWxD) amounted to 117 x 385 x 60 mm, while a further 117 x 330 x 60 mm was needed for the AVAT components. A typical system comprises:

- control and monitoring of all engine processes
- control of engine cooling circuit, intercooler and emergency cooler including dry coolers
- cylinder-individual knock and misfire control
- CAN interface to ignition system
- SCADA interface (Modbus TCP).

For a 10 MW class dual-fuel marine engines with port injection engine, significantly more sensors and I/O modules are used. To avoid long cable runs the I/O for the gas control path and auxiliaries were moved to a separate panel and connected via the Ethernet. Due to marine regulations, a safety unit likewise made up of PLC modules, redundant Ethernet and CAN communication and monitored signal cables to the bridge were implemented. The marine versions of AVAT's E²PRECON-M and E²KNOCKCON-M are employed for cylinder pressure and structure-borne sound analysis. Features include:

- CAN interfaces to injection control units
- cylinder pressure based engine control including cylinder balancing and peak pressure (P_{max}), knock and misfire monitoring.
- additional anti-knock governor with standard knock sensors
- two operating panels (local/remote).

The ECS with engine I/O and safety unit was installed into a compact control cabinet and was fitted directly onto the engine. As shown in **FIGURE 11**, fulfilment of the exacting vibration requirements was validated during test runs on a vibration test stand.

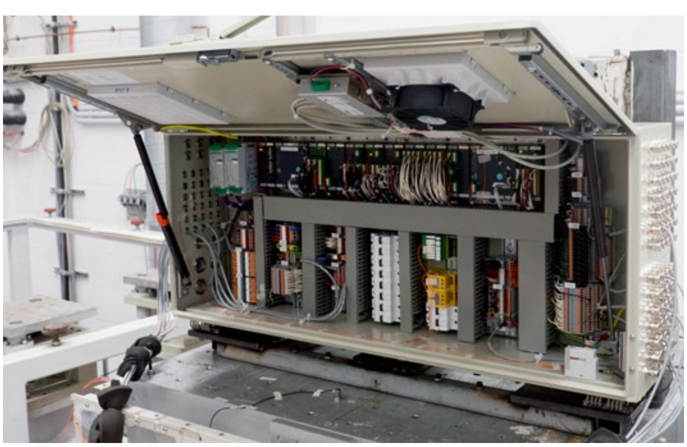


FIGURE 11 The openECS engine control panel on the vibration-test stand (© AVAT)

CONCLUSIONS

Smart engines will certainly come which are both capable of integration into networks with hybrid or virtual applications and are themselves capable of collecting data for central evaluation. "Smartification" will lead to improvement and individualisation of products and to a further acceleration in product development. In this process, software will play the central role.

The devices, software modules and services of the new openECS platform, developed in cooperation with Bachmann electronic GmbH, are tailored to the needs of engine builders and plant engineering companies who use professional tools to produce high value software, or wish to do so in the future. To facilitate a fast start of development, templates for typical engine configurations or complete customer-specific ECS applications are provided in source code.

Key to the development of the new platform was an appraisal of all the processes affecting the writing, updating and delivery of software in collaboration with the end-user. In this way it was possible to minimise sources of errors and considerably simplify and automate activities. Lean processes and tools are not only the precondition to rapid development times; they also promote new modes of cooperation by which variable developer resources can be used to realise ever larger projects.

REFERENCES

[1] Porter, M.E.; Heppelman, J.E: How smart, connected products are transforming competition. Harvard Business Review, 11/2014
[2] www.plcopen.org