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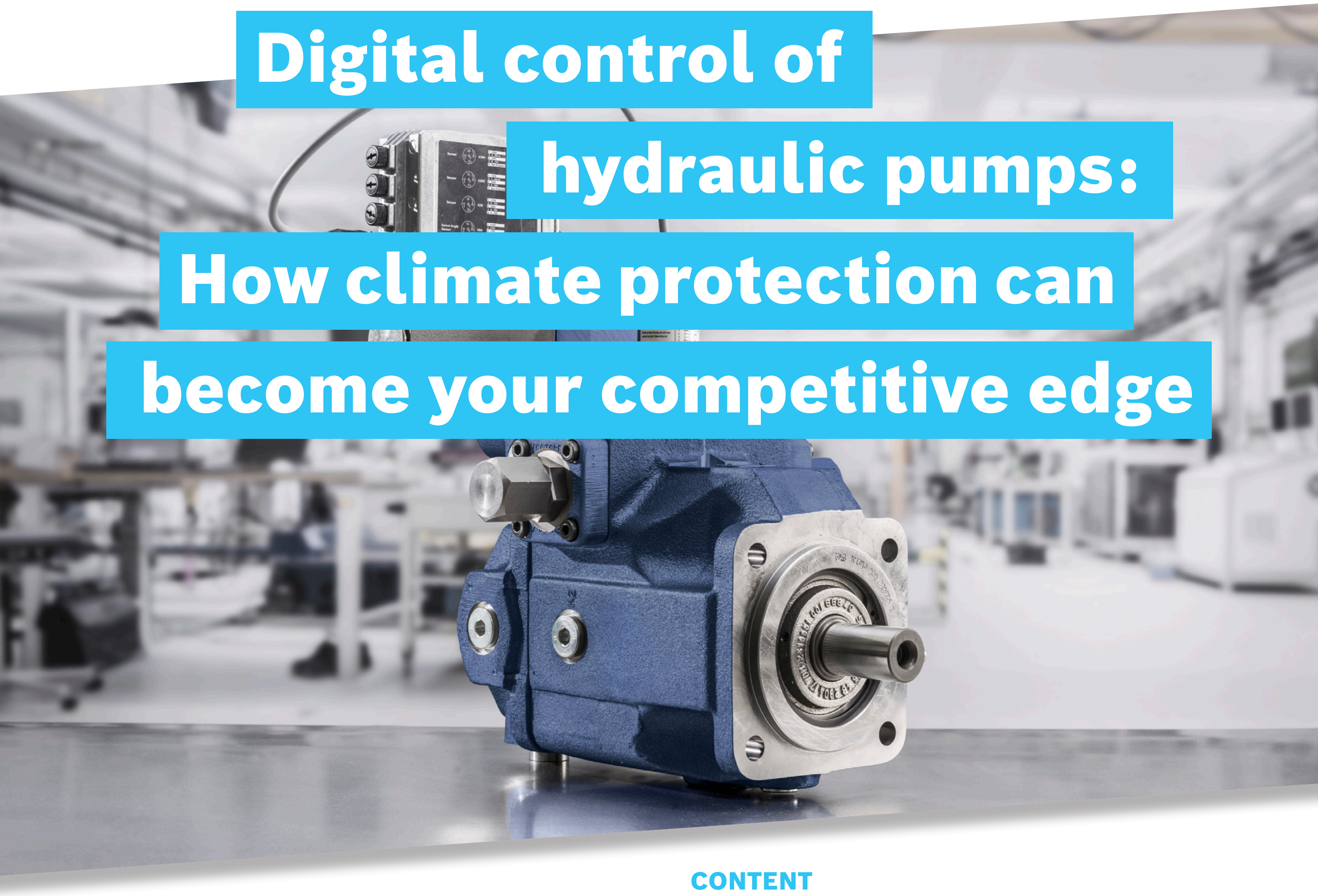
Digital control of hydraulic pumps: How climate protection can become your competitive edge



The two megatrends of climate protection and digitalization are challenging the hydraulics industry and becoming a driver for technical innovation. Intelligent variable pumps and variable speed drives make a significant contribution to greater energy efficiency, productivity and availability. Find out why this is the case and how to find the optimal solution for new machines and existing systems in this white paper.

CONTENT

1. INCREASING CLIMATE PROTECTION AND PERFORMANCE. IS IT POSSIBLE?

In many industries, there are no alternatives to hydraulic drives in terms of power density. At the same time, the fight against climate change calls for greater energy efficiency to reduce CO_2 emissions and meet the 1.5-degree target of the Paris Agreement. For manufacturers of industrial hydraulic systems, this means building machines that are both climate-friendly and competitive. Mastering this balancing act requires innovative technologies. Machine users, in turn, are looking for ways to optimize their system inventory and at the same time make their own contribution to climate protection. The EU wants to be climate neutral by 2050, China by 2060. Climate protection initiatives such as the „European Green Deal“ are setting concrete modernization incentives through CO_2 taxes and subsidy programs.

What does this mean for industrial hydraulics? How can climate protection and productivity be combined? The answer to this question is given by another megatrend: digitalization. Intelligent control concepts pave the way for new, pioneering machine concepts. Millions of hydraulic pump drives in the field can become more energy efficient, while also being more productive, feature greater availability and durability. Digitalization can significantly simplify processes along the life cycle and reduce overall costs.

Green technologies for green business

Modernization of production technology is one of the biggest levers in climate protection. According to a joint study by Boston Consulting Group and VDMA, annual greenhouse gas emissions can be reduced by up to 30 gigatons by 2050, starting from around 51 gigatons in 2020. Mechanical engineering plays a key role here because, in addition to new energy-efficient systems, it also offers retrofits for energy optimization of existing systems. Digital pump controls can save up to 80 percent of the previous energy consumption compared to conventional solutions and avoid CO_2 emissions accordingly.

More on this topic can be found in the Rexroth white paper „These three levers make your fluid technology more environmentally friendly and more economical too.“

2. INTELLIGENT PUMP CONTROLS

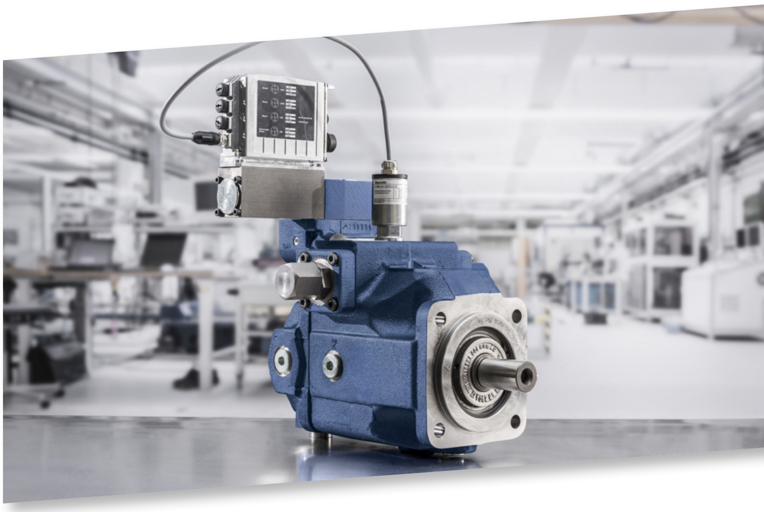
The biggest lever for climate-friendly hydraulics is energy efficiency. Controlling flow by pump displacement or drive speed significantly reduces power consumption.
Pressure losses of conventional throttle controls are avoided, less energy is converted to heat and more energy remains for the process. Intelligent pump drives are also characterized by the fact that they adjust the flow to the actual demand of the consumers. This in turn reduces electricity costs and CO_2 emissions. In principle, there are two solution approaches:

2.1. Variable displacement pump
Variable displacement pumps adjust the flow via swivel angle control (displacement of the pump). This principle works with both constant and variable drive speed.
The main features are:

- Swivel angle control with and without drive speed adjustment
- High-resolution, stepless control through extensive, electronic controller functions
- Digital electronic controllers for higher accuracy requirements and more complex control functions
- Hydraulic/mechanical controllers for lower accuracy requirements and less complex control functions

2.2. Variable-speed pump drive
Variable speed-drives adjust the flow via speed control (electric motor). The main features are:

- Speed control (electric motor)
- Works with both fixed displacement and variable displacement pumps
- Lower control accuracy with asynchronous motors
- Higher control accuracy with servo motors
- Possible combination with hydraulic/mechanical controllers (variable displacement pump)



▲ **A4 pump with HS5 control**

2.3. Combined solutions and distinction
Both control types can open up new potentials: By means of swivel angle control, for example, the drive speed can be controlled (n-functionality) to further reduce power consumption as well as noise emissions (low flow requirement). For speed controls, variable displacement pumps offer the advantage of reducing the required drive torque, which allows the use of smaller and more cost-effective electric motors (lower flow requirement at higher pressures).

Whether a solution with a digitally controlled variable displacement pump or a variable-speed drive is suitable depends on the one hand on the cycle and on the other hand on the size of the pumps to be used. Load profiles with continuously cycled processes and short to no rest periods are generally better realized with electronically controlled variable displacement pumps. Load profiles with longer pressure holding phases with minimum flow requirements are better realized with speed-controlled drives. Dynamic adjustment of the flow requires time and (actuating) energy. While variable displacement pumps require the adjustment of the swivel angle, variable speed drives require the acceleration of the rotating masses of the electric motor and pump. Depending on the size, one of the two solutions has the advantage – for orientation:

> 160 kW: tendency towards swivel angle control (variable displacement pump)
< 160 kW: tendency towards speed control (speed-controlled drive)

Manufacturer-specific software tools such as the Size&Select Assistant from Rexroth provide support in finding the respective system limits.

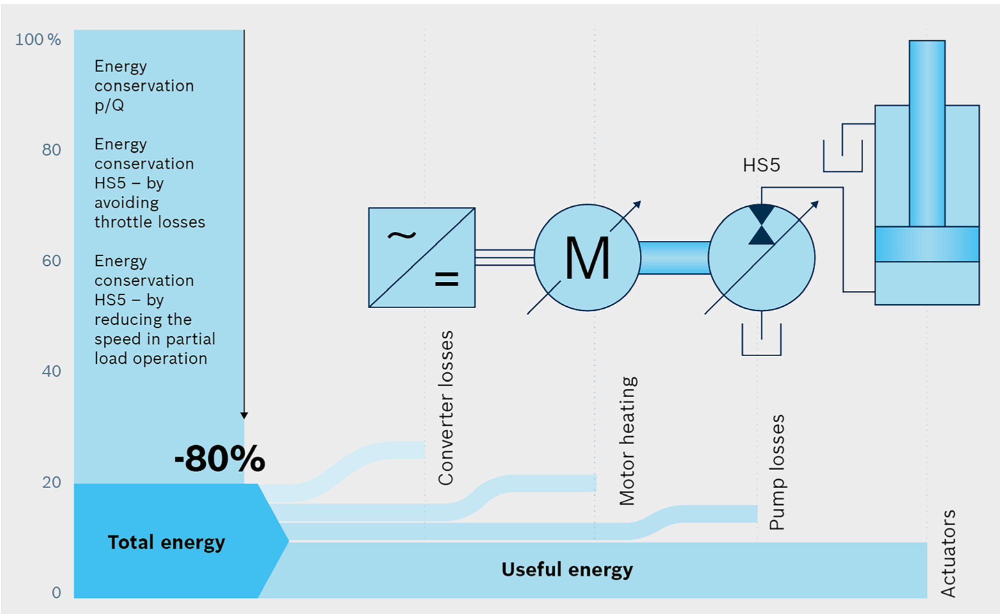
3. WHY DIGITALIZATION PAYS OFF

3.1. Condition monitoring for higher system availability
Machine builders and system operators alike have interest in high overall system availability. This key figure, also known as Overall Equipment Effectiveness (OEE), quantifies the effectiveness of the factors availability, output, and quality for each individual machine. The value grows with increasing reliability of all technical components, rising productivity of the system and increasing precision of the processes.

When it comes to availability alone, hydraulic pumps generally have a lot to offer. They are low-maintenance and feature a very long service life if the operating medium is well maintained. Thanks to digitalization, integrated monitoring functions within the control electronics simplify fault diagnosis, provide all information and operating states via an Ethernet TCP/IP service interface. They help to avoid unplanned downtimes with high failure costs, even for variable-speed drives. Finally, the motor-pump combinations, which always run at the optimum operating point, have a positive effect on the service life of shaft bearings and downtimes of hydraulic fluids.

3.2. Energy-efficient and quiet operation
Combined with digital electronically controlled variable displacement pumps including n-functionality, energy consumption can be reduced by up to 80 percent compared to constant systems. On the one hand throttling losses are avoided, and on the other hand pressure and flow are controlled, torque is limited dynamically and precisely to the actual demand. Rexroth's modular SY(H)DFE control systems, based on proven A10 and A4 axial piston pumps, are well known examples, which have been installed hundreds of thousands of times in machines and systems. They work like hydraulic gears using stepless displacement control of the pump – and speed control of the drive motor where required.

▼ **New level of energy efficiency: A steplessly adjustable "hydraulic gear" consisting of speed and displacement control requires significantly lower installed power.**

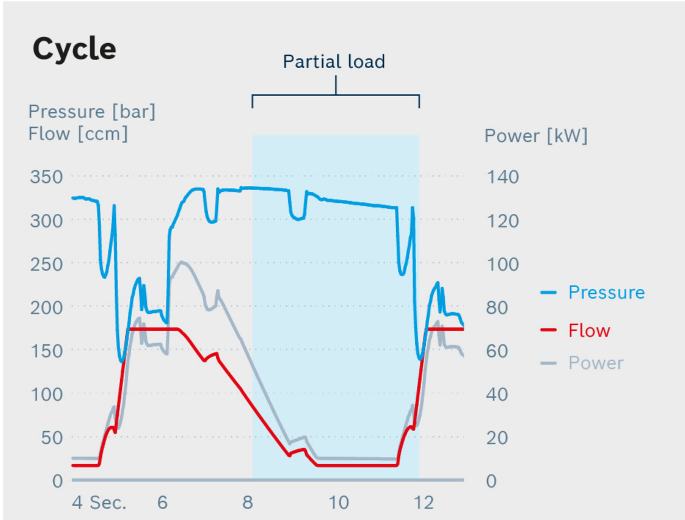


The decisive parameter for the energy-saving potential is the time share of partial load operation in the cycle. During this time period, the flow or power requirements of the machine are low. To keep the axial piston unit at a swivel angle which, on the one hand, is within the range of good efficiency and, on the other hand, provides sufficient swivel reserve for highly dynamic flow increase, Rexroth's „n-function" software always calculates the lowest possible speed based on the required flow. This saves energy in two ways at once: Firstly, by demand-oriented provision of flow, secondly by avoiding throttling losses.

In addition, speed control also reduces average noise emissions by up to 20 dB(A). This allows secondary noise control measures to be reduced or to be no longer needed.

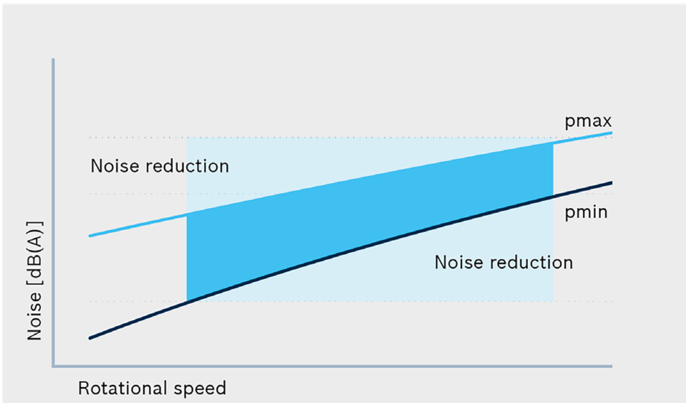
3.3. More productivity, lower costs (downsizing, engineering, design)

If an electric motor is connected directly to the power supply, the drive speed is determined by the supply frequency. In many cases, however, variable displacement pumps may be operated at higher speeds. If the speed of the electric motor is increased via a frequency converter, the flow or hydraulic power generated by the pump is proportionally increased. The resulting higher hydraulic power can be used either to increase the system productivity or to „downsize" the drive components, as shown in the downsizing example on the following page.



▲ **Application cycle**

▼ **Noise development depending on speed and pressure**

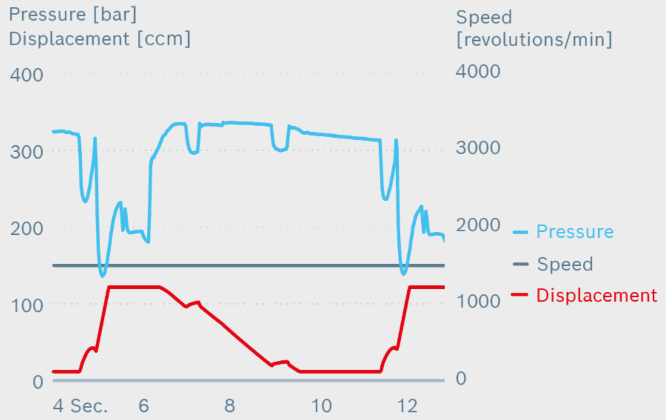


The maximum required flow is approx. 175 l/min (see application cycle). At a drive speed of 1500 rpm, a displacement of at least 120 ccm is required. In this case, an **A4VSO 125** with a maximum speed of 1800 rpm is necessary. At a drive speed of 2540 rpm, 71 ccm of displacement is already sufficient and a **H-A4VSO 71** with a maximum speed of 3000 rpm can be used. This enables downsizing from 125 ccm to 71 ccm.

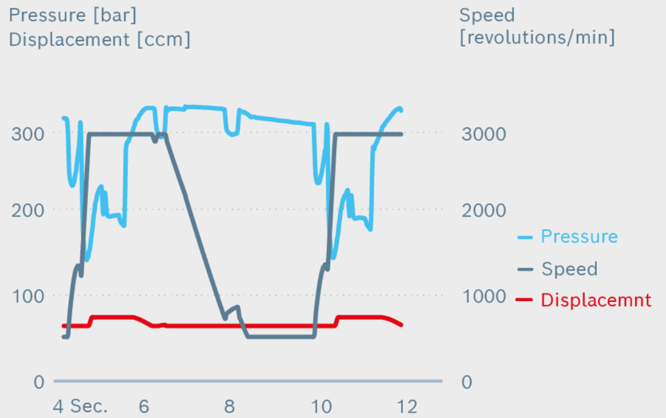
The maximum power needed is approx. 105 kW. At a drive speed of 1500 rpm, an electric motor with a drive torque of at least 700 Nm is required. With electric motors, the drive power increases almost proportionally with the drive speed, so that a small electric motor with a lower drive torque can also be used. This is because, as previously explained, the same flow can be generated with lower displacement at a higher speed. The required drive torque decreases proportionally with the displacement. The torque limiting function of the control electronics prevents any overload.

In the illustrated example, the drive torque is halved from 700 Nm to 350 Nm. Instead of an electric motor with 110 kW, a motor with 55 kW is now sufficient (specified power related to the speed of 1500 rpm).

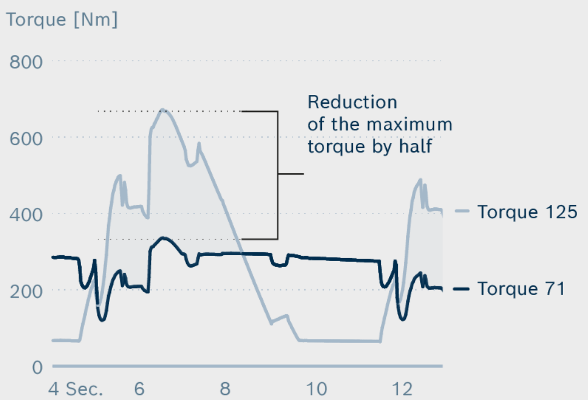
Axial piston variable pump A4VSO 125



Axial piston variable pump H-A4VSO 71



Torque curve



Reduced cooling effort

Variable speed pump drives usually require less cooling. The reason for this is the reduced power loss and lower heat input. This means that the hydraulic fluid is subject to less thermal stress and a longer service life is achieved. Fluid change intervals become longer and open the possibility of reducing the cooling capacity to be installed. Smaller or, at best, no cooling units respectively reduce costs and save space.

Less space requirements

Compact design of the pump control system, require less valuable installation space in the machine and/or in the control cabinet. In addition, hydraulic circuit can be significantly simplified, which in turn reduces the cost of hydraulic components. The reduced space requirement applies to both the variable displacement pump and the electric motor.

3.4. Mastering and reducing complexity

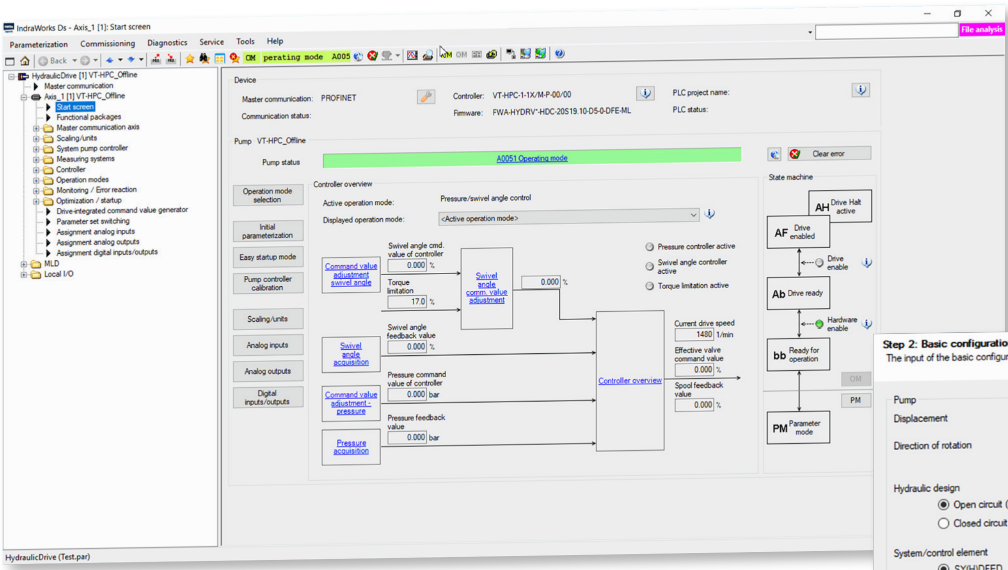
Digital, electronic controllers have a large number of parameters to perform the respective control function in the best possible way. These mainly include pressure and swivel angle control, torque limitation and master-slave operation (several pumps are operated like one single large pump) as well as speed open control (n-functionality). Besides, different processes can be optimized with high precision and reproducible control behavior, when parameter sets are predefined and intelligently switched during operation.

Handling and reduction of complexity becomes more important, as the number of control parameter for a best possible machine integration gets higher.
For this purpose, Bosch Rexroth developed the IndraWorks engineering platform for uniform application across all products. It enables not only machine builders but also end users to select necessary settings and perform engineering, commissioning and (fault) diagnostics in a simple and efficient manner.

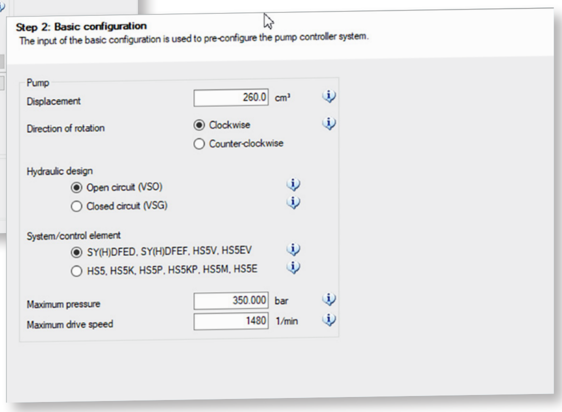
IndraWorks standardizes the handling of PLC, motion, and all drive technologies for all Rexroth systems, thus ensuring the same „look & feel“ for every kind of programming.

The commissioning wizard provides quick and targeted guidance through initial parameterization. This allows quick connection of the pump to the machine control. In addition to the configuration of pump-specific parameters for communication with the machine control, the initial parameterization also includes the automatic calculation of control parameters. This provides a good basis for further system optimization and in many cases already leads to sufficiently high control quality.

Pumps with on-board electronics are configured regarding pump-specific parameters and calibrated already ex works. By sending analog command values, the pump or the control system is immediately ready for use (plug & produce). Bosch Rexroth‘s experts provide support not only in engineering but also in solving complex problems. The worldwide service remote support includes Ethernet access to digital control systems. In addition, Bosch Rexroth offers a wide range of (online) training courses as part of the „Bosch Rexroth Academy“ to build up or expand know-how.



◂ Start screen of the IndraWorks cross-technology engineering platform



▸ Parameterization instead of programming: Wizard-supported assistance functions provide logical and targeted guidance through commissioning in just a few steps.

4. FLEXIBILITY THANKS TO MODULAR SYSTEMS

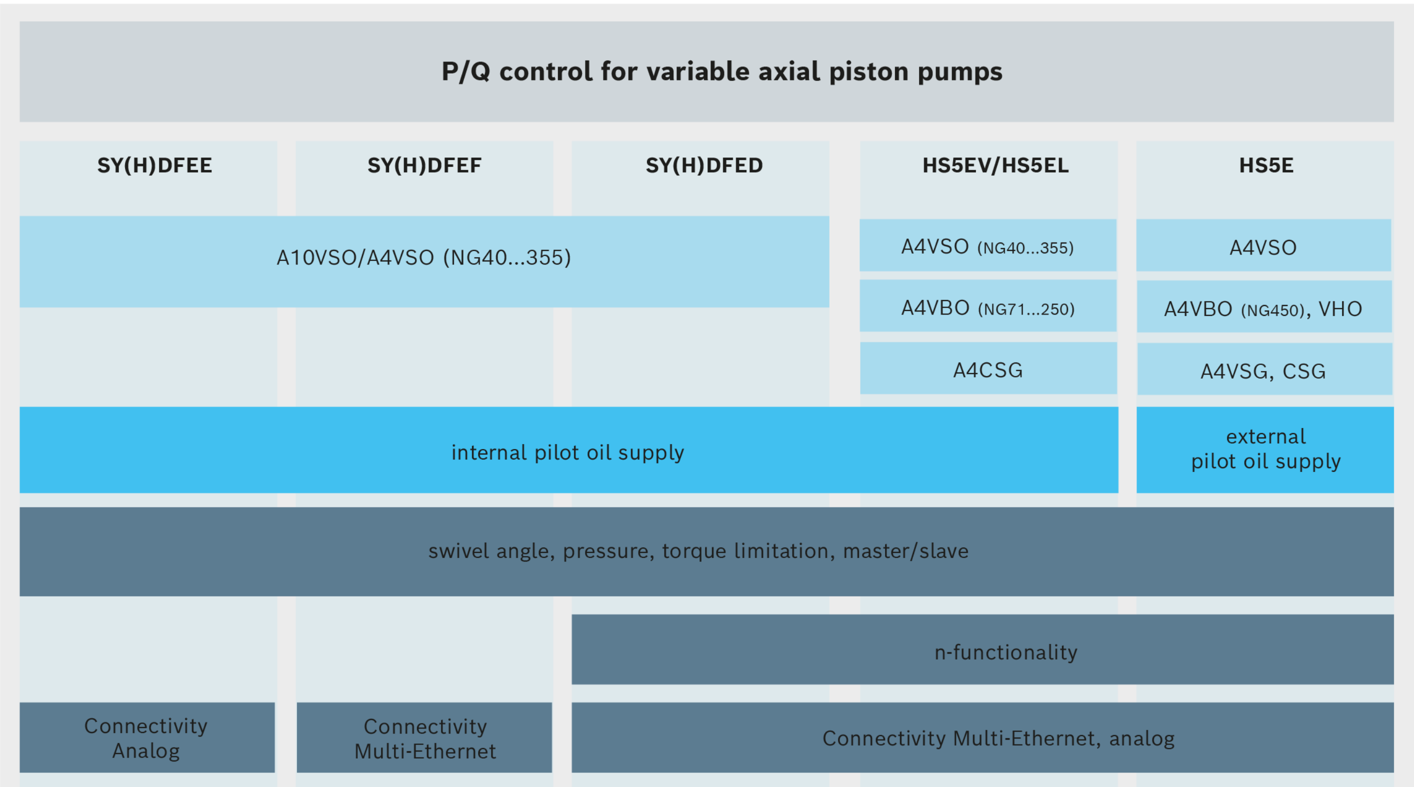
Bosch Rexroth offers an extensive modular system where machine and system manufacturers will find solutions for almost every individual requirement. The „Digital Electronics“ category includes the modular SY(H)DFE control systems for the A10 program and certain A4VSO types, as well as the HS5 control system for the complete A4 program. Both programs are continuously expanded and supplemented.

New to the portfolio, for example, is the A4VSO high-speed version of axial piston variable pump size 71, especially designed for variable-speed applications. Compared to standard version, speeds of up to 3000 rpm are feasible without supply of boost pressure and means an increase of more than 35%. This enables downsizing of the electric drive and significant cost reduction. For applications with high nominal pressures up to 450 bar, Bosch Rexroth has also developed the particularly quiet and robust A4VBO variable displacement pump in size 250 with axial piston rotary group in swashplate design.

To offer designers maximum flexibility, the modular system for pump control systems is divided into the following two groups:

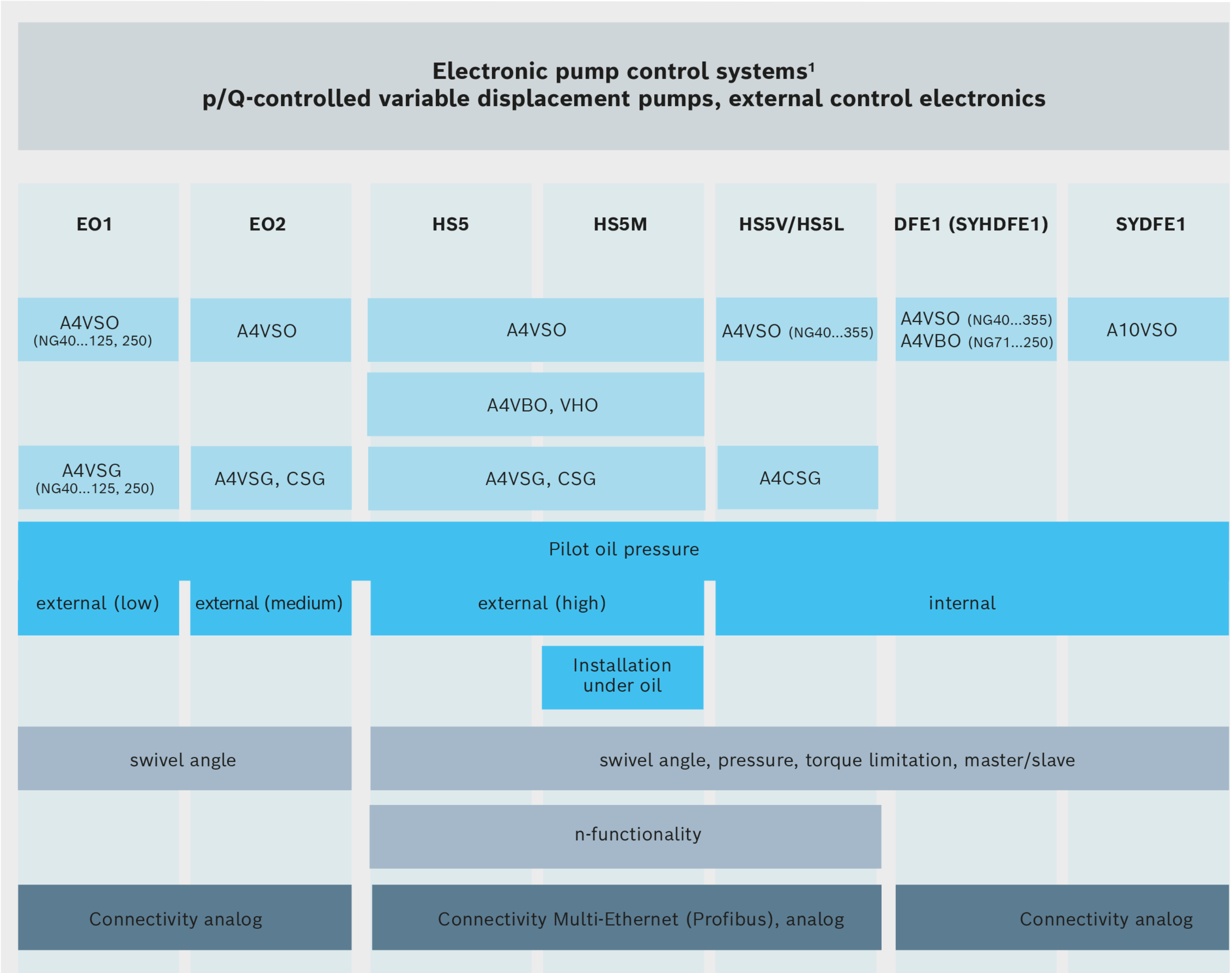
4.1. On-board electronics (OBE) – without control cabinet

Electronic control systems directly connected to the pump fall into the on-board electronics (OBE) category, i.e., without a control cabinet. On-board electronics (OBE) are used in SYHDFEx (H = A4) control system and HS5E control system for A4 variable displacement pumps as well as SYDFEx system (without H) for variable displacement pumps of the A10 range. As factory completed systems with robust M12 connectors, all OBE variants are ready to „plug & produce“ and fulfill all requirements for reliable operation. Another advantage is flexible arrangement of pumps within the machine saving installation space.
The size of the control cabinet can be reduced as well as the time and cost required for wiring. Since the electric installation is simplified, material costs are reduced and there is less potential for faults. In addition, there is less disruptive influence due to reduced cable length to the sensors (EMC).



▲ **Features of electronic pump control systems with internal control electronics**

4.2. Control cabinet electronics



▲ **Features of electric pump control systems with external control electronics ([1] Without secondary control, for further information see data sheet 92057)**

VT-HPC is the control cabinet electronic for HS5 control systems with the same range of functions as the OBE variant. As the n-function is provided via SD card (amplifier card), it can also be retrofitted. The advantages of control cabinet electronics come into play particularly in case of

- **excessive mechanical stress on electronics on site**
- **excessive thermal load on the machine (air-conditioned control cabinet).**

5. DECISION MAKING – FINDING THE RIGHT PUMP CONTROL

Various factors must be considered during the decision-making process to find the best variable displacement pump solution for the desired machine concept.
The following questions are important for the decision-making process, in the order they are presented in:

1. Should an on-board electronic (see chapter 4.1: OBE solution) or a control cabinet electronic (chapter 4.2: Control cabinet solution) be used? If the environmental conditions allow an OBE operation, we recommend to benefit from OBE advantages. If the conditions do not allow an integrated solution or if the installation is to be carried out under oil, the control cabinet electronic system needs to be used.

2. What is the optimal variable displacement pump solution? The question here is whether it is to be used in an open or closed circuit.

3. What pressure level and flow are required?
This decides the type and size of the pump.

4. Is a dynamic dependent on the system pressure permissible? Depending on the answer, the pilot oil supply is either internal or external.

5. Is speed variability (n-function) useful in addition to swivel angle control?

6. How is the communication realized? In most cases, fieldbus systems such as Sercos, EtherCAT, EtherNet/IP, VARAN, PROFINET or optionally Profibus are required. In some cases, analog master communication might be sufficient.

6. INVENTORY OPTIMIZATION: UPGRADE, RETROFIT OR RE-ENGINEERING?

Depending on the scope of the planned modernization, the variable displacement pump installed and its condition, there are several options:

1. **Upgrade:** Has a pump with electro-hydraulic control HS or the previous versions HS3 or HS4 already been installed? In this case, the pump can be easily upgraded by replacing the swivel angle sensor, control valve and digital control electronics (on-board electronics or external electronics). The components are installed on the outside of the pump housing and can be replaced without removing the pump if this is permitted by the installation situation in the system. Commissioning takes place directly after wiring. Suitable upgrade kits are available from Bosch Rexroth.
2. **Retrofit:** For pumps with a different control system, the conversion effort should first be evaluated. If this is economically, the conversion should be carried out by Rexroth Service.
3. **Re-engineering:** If a fundamental overhaul of the hydraulic system or the higher-level machine control system is required, the experts at Bosch Rexroth will draw up appropriate proposals.

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7. CONCLUSION

Demand-based pressure and flow control provides an effective basis for greater energy efficiency, contributing to both climate protection and lower operating costs in terms of economic efficiency. At the same time, it also reduces noise emissions for better occupational health and safety. The bottom line is that no less than overall system efficiency benefits from digitalization: The higher control quality enables processes with higher precision, improved efficiencies increase productivity, and availability is also increased by faster fault diagnosis and optimized maintenance.

In addition, costs are reduced along the entire life cycle: Thanks to the uniform and intuitive IndraWorks engineering platform, engineering becomes less complex and gains flexibility in design for individual and customized machine concepts. The commissioning is made easier and faster by wizards to guide users, and installation requires less time and material. Finally, digitalization also raises service to a new level, for example with worldwide remote support.

Under these conditions and supported by national funding programs for more energy efficiency, investments in digital pump control systems quickly pay for themselves and become an important driver of climate protection, innovation and competitiveness.

More information can be found under
www.connected-hydraulics.com

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8. APPENDIX

Flow $$q_v = \frac{V_g \times n \times \eta_v}{1000} \quad [l/min]$$

Torque $$M = \frac{V_g \times \Delta p}{20 \times \pi \times \eta_{hm}} \quad [Nm]$$

Power $$P = \frac{2\,\pi \times M \times n}{60000} = \frac{q_v \times \Delta p}{600 \times \eta_t} \quad [kW]$$

Key

V_g	=	Displacement per revolution [cm^3]
Δp	=	Differential pressure [bar]
n	=	Rotational speed [rpm]
η_v	=	Volumetric efficiency
η_{hm}	=	Hydraulic-mechanical efficiency
η_t	=	Total efficiency ($\eta_t = \eta_v \times \eta_{hm}$)

▲ **Relationship between flow, torque and power as a basis for increased plant productivity or "downsizing" of drive components.**

Product information

	Flow	Pressure level	Pump version	Rexroth data sheet
open	104 - 1.125 l/min	350/400 bar	**A4VSO** (NG 40 – 1.000 ccm)	92050
open	156 – 810 l/min	450/500 bar	**A4VBO** (NG 71 – 450 ccm)	92122
open	bis 675 l/min	630/700 bar	**A4VHO** (450 ccm)	92160
closed	148 – 1.600 l/min	350/400 bar	**A4VSG** (40 – 1.000 ccm)	92100
closed	550 – 1.200 l/min	350/400 bar (with integrated valves and boost pump)	**A4CSG** (250 – 750 ccm)	92105

▲ **In which circuit is the pump used?**