Energy-efficient & modular compressed air systems with MTP (Modular Type Package)

INVITE GmbH | Sustainability & Innovation

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In an increasingly resource-constrained world, the need for sustainable innovations and solutions is more pressing than ever in industry. The efficient use of our energy sources is a decisive step towards ensuring long-term competitiveness and global environmental integrity. One of the first levers is the treatment of industrial compressed air system.

Compressed air system is a major energy consumer, and depending on the company, energy consumption can account for up to 80% of the costs in the 10 year life cycle of a compressed air system.[1] Compressed air accounts for as much as 10 % of industrial electricity consumption, that is more than 80 TWh per year in the European Union. In conjunction with rising electricity prices, which have increased by 75% for industrial consumers in Germany over the last ten years and could more than double in times of crisis (2021-> 2022 | +150%), there is an urgent need for energy-saving concepts. [2]

In addition, oversizing compressors often poses a major challenge for the efficient operation of compressors. When designing compressors, most industrial companies include additional factors to allow for future expansion. Failure to utilize these additional resources often leads to higher specific energy consumption and wear of mechanical elements, as optimal operating points are not approached. Another problem with air compressors is frequent maintenance due to the immature control strategy and the lack of monitoring of process parameters such as pressure, temperature, energy consumption and other internal vitality data to predict faults and avoid inefficient operating states.

Where is compressed air used in the pharmaceutical industry?

In the pharmaceutical industry, active ingredients are produced and processed into tablets or liquid medicines. A major consumer of compressed air is fermentation, in which microorganisms or other organic material are cultivated into important medicines such as antibiotics, therapeutic proteins, enzymes and insulin.[3] Compressed air is also used for drying, hardening, coating, and packaging in the further processing of tablets and pills in their final form. As the drugs come into direct contact with the compressed air in all these process stages, it must be free of residues as possible and therefore generated in oil-free and air-cooled compressors- even if the use of these is associated with higher energy consumption.[4] Furthermore, compressed air treatment in the pharmaceutical industry in particular is characterized by the fact that demand is subject to very strong fluctuations depending on the process stages involved.

Modularization- The way to more efficient use of air compressors in industry!

Dynamic demand of high-quality air, and rising energy costs are increasingly raising the question of how compressed air can be provided in a process-reliable manner with low acquisition and operating costs, while at the same time enabling energy efficient process and preventive maintenance.

Thanks to the standardized interfaces for the integration of air compressors, a modular concept can be developed using the Module Type Package (MTP), which combines the advantages of distinctive designs and drive types in a single system and meets the complex requirements for implementing control strategy with a minimum of development work during installation. MTP can be a way to develop better automation, supply and quality management, and maintenance concept to effectively design a system that meets peak requirements but also operates efficiently at part-load to achieve a high-performance compressed air system.

In a system with several compressors, a sophisticated control system is used to coordinate the compressors and the air supply to the system. A central control system coordinates all the functions required to provide and optimize the compressed air supply. An autonomous master control strategy provides various functionalities, including monitoring, controlling the components in the system, and collecting trend data to improve maintenance functions and minimize energy consumption and operating costs. The concept of this white paper is that two different drive types of air compressors can be combined in a network and their respective advantages can be used in combination to serve the dynamic demand. These two drive types are the Variable Speed Drive (VSD) and the Fixed Speed Drive (FSD).

The FSD compressors can regulate the operating pressure by means of switch-on and switch-off intervals (two-point control). However, due to the mechanical load during start-up, they cannot be switched off completely during the switch-off interval, but instead run idle. FSDs cannot handle frequent start/stop and are limited to four starts per hour to avoid damage to the motor. This type of compressor usually consumes 15-35% of the energy in idle mode and can therefore lead to poor efficiency in the event of unfavorable compressed air requirements (long switch-off intervals). Under full load, however, this type of drive has the highest energy efficiency.

The drives of VSD compressors are controlled by frequency inverters so that they can continuously adapt to the compressed air demand from a minimum flow rate and thus enable a stable operating pressure with constant energy efficiency. They also benefit from reduced stopping and starting stress due to the soft start facility and allows unlimited motor starts per hour. However, VSD compressors have a slightly higher energy requirement at the same delivery rate than FDS compressors at full load. In addition, the use of VSD compressors is associated with higher procurement and maintenance costs.

By modularizing air compressors, the advantages of both types can be combined – optimal design, minimal maintenance and acquisition costs, and the good efficiency of FSD compressors at full load with the precise and energy-efficient regulation of pressure by VSD compressors. Compressors with fixed and variable drive systems have dynamic energy consumption profiles. They require master control strategy to run the multiple compressors as a system. The control system with energy optimization reacts to the flow and pressure of the air output and determines which compressors need to be loaded and which ones need to be unloaded to have the most energy efficient configuration. Several FSD compressors initially serve the main load and can be switched on and off individually when the main load changes (no idle consumption). A VSD compressor can regulate the exact operating pressure via the residual demand. This enables the highest possible efficiency in the control of the compressors. The control of the air compressors can be designed according to the scheme shown in Figure 1.

The maximum flow rate of the system is the sum of the flow rate of the VSD compressor and the flow rates of the integrated FSD compressors. VSD is a promising option when the load is dynamic and fluctuates regularly or when it is used to provide top-up capacity. If the upper or lower limit of the VSD compressor's operating range is reached, the control system switches a FSD compressor on or off. The capacity of the VSD and FSD compressors in the network should be selected so that the capacity of the working range of the VSD compressor (the difference between the flow rate at full load and lowest load, usually approx. 40 to 100%) is greater than the capacities of the individual FSD compressors.

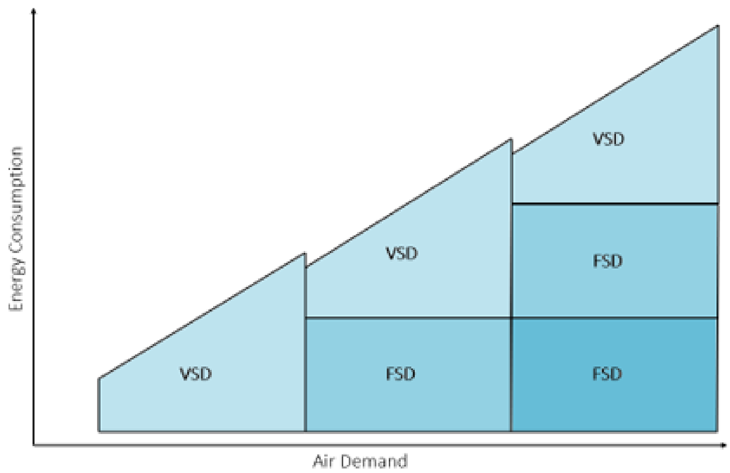

Figure1: Modular network for compressed air system (1 VSD + 2 FSD)

If the operating range of the VSD compressor is even significantly larger than the capacities of the FSD compressors, the switching limits for the FSD compressors can be selected using an optimization algorithm based on the characteristic curve for the specific energy consumption of the VSD compressor so that the VSD compressor operates in the most efficient range (see Figure 2).

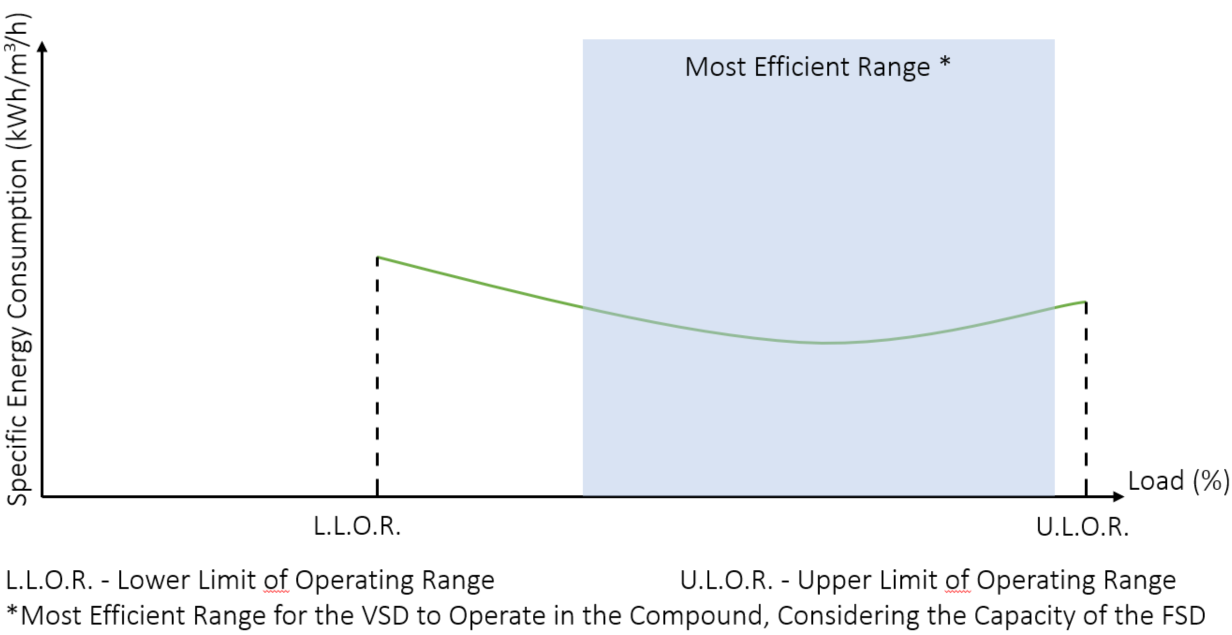

Figure 2: Optimizing the control of the VSD compressor

A correctly programmed controller can determine the best and most energy-efficient response to events in the network. The number of compressors to which a controller can be connected depends on the practical requirements and financial possibilities. When determining the sequence in which the FSD compressors are to be switched on and off, sustainable, and material-friendly handling of the machines can be aimed for, e.g., by actively distributing the working hours equally.

What role does MTP play in the modularization of air compressors?

As the network of compressors and the associated components is spatially and functionally self-contained, it makes sense to describe the central control of the network in a standardized way using a Module Type Package (MTP). This enables the direct integration of the user interface and the complex functionalities into a process control system. The integration and disconnection of individual compressors is carried out separately from MTP using internal functionalities in the central control system.

The standard divides a modular system structurally into two parts - the PEA and the POL. The PEA (Process Equipment Assembly) comprises a production unit that is self-contained and can perform services (functions or operations) independently. For this purpose, the PEA has its own controller, which controls communication with the POL in addition to the internal processes. The POL (Process Orchestration Layer) monitors and coordinates the services of the integrated PEAs as a higher-level instance. To integrate the PEA into the POL, a MTP file is used in which the interfaces and the structure of the HMI (Human Machine Interface) of the PEA are described in a standardized manner. This file is generated in parallel with the configuration and, if necessary, programming of the control system and then transferred to the POL. Based on the MTP file, the POL generates the HMI in the application interface of the process control system and establishes a connection to the OPC UA server of the PEA.

A concept for implementation could envisage that the master control system of the network forms the core of a PEA together with a VSD compressor. The controller then provides several open control channels via which FSD compressors can be flexibly integrated into the PEA. The number of FSD compressors is based on the anticipated maximum compressed air requirement and can be adjusted without interruption at the process control level as new requirements arise (hot swap). The FSD compressors are intelligently switched off and on by the PEA control system to meet the basic compressed air demand with the highest possible efficiency and to regulate the exact operating pressure over the residual demand with the VSD compressor. To do this, the master control system acts as a central unit to coordinate all processes in the network.

What does the structure look like in detail?

Specifically, the tasks of the master control system include switching on and off FSD compressors, determining the ideal setpoint of the VSD compressor, and monitoring and evaluating the process and vital parameters of the system (pressure, working hours, air quality, temperature, energy consumption and subsequent efficiency). Taking these parameters and the configuration of the compressors into account, the control system switches the FSD compressors as efficiently and with as slight wear as possible and regulates the utilization of the VSD compressor to ensures the energy efficient operation. In addition, the controller processes all recorded parameters to publish them in an OPC UA server for diagnostic methods and the determination of preventive measures against failures by a higher-level application on the one hand and to transmit a collection of parameters to the operator in a clear manner via the HMI on the other.

Figure 3 shows a possible structure of the concept. Due to the significant role of the VSD compressor in the network, it is permanently connected to the control system as a central unit during operation. The VSD compressor is configured according to the manufacturer's data sheet directly when programming the control system and is therefore permanently implemented. The configuration of the FSD compressors is carried out dynamically by the operator via the HMI.

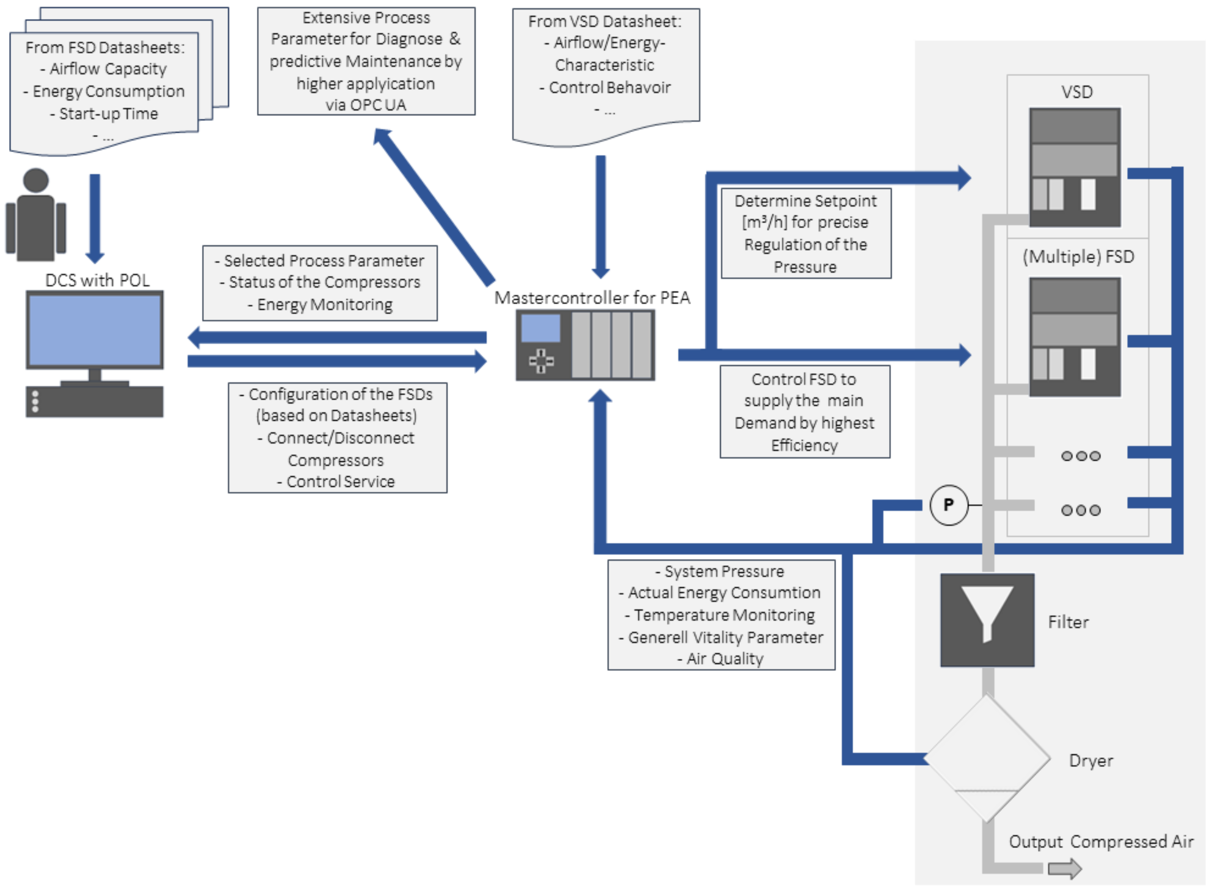

Figure 3: Schematic diagram of a modular compressor design

What does the HMI look like and what are the operator's tasks?

In addition to integrating the network into the process control system, the only effort required by the operator is to integrate the FSD compressors into the network via the HMI depending on the expected compressed air requirement and to configure them using the relevant data sheets. Due to the simple control and parameterization of FSD compressors compared to VSD compressors, they can be flexibly configured during operation via the HMI in the POL without much effort. There are dedicated interfaces in the HMI for each FSD channel. The required process parameters of the VSD compressor and general process parameters of the system relevant to the operator are displayed in another interface (Figure 4). The service for autonomous control of the compressors and regulation of the system pressure is also selected in the HMI.

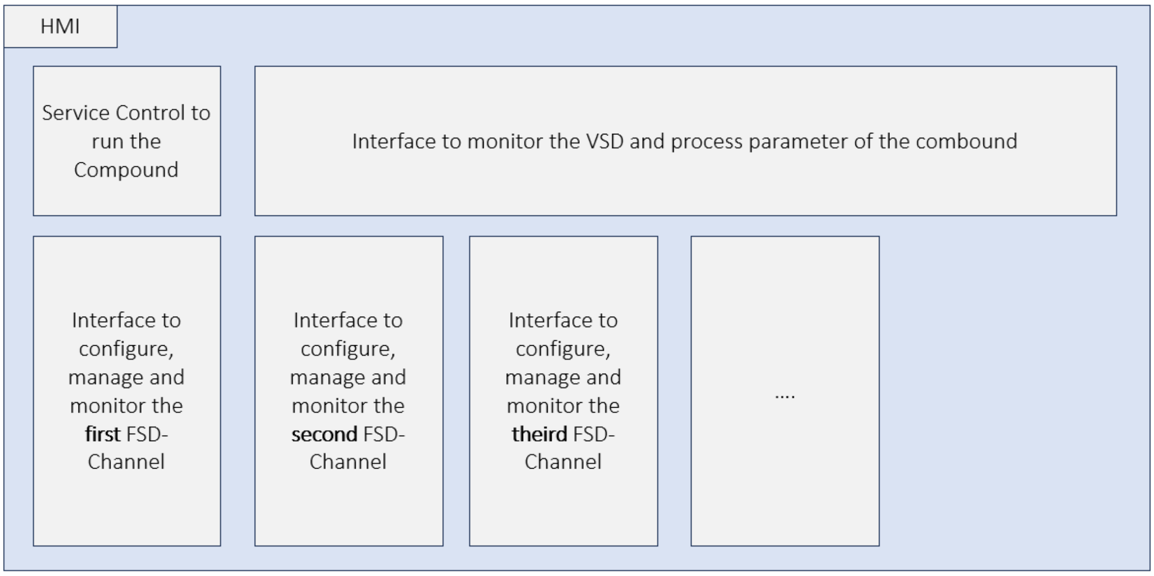

Figure 4: HMI of PEA

Within the surfaces of the FSD channels, the compressors can be integrated and separated, as well as configured and monitored, see Figure 5.

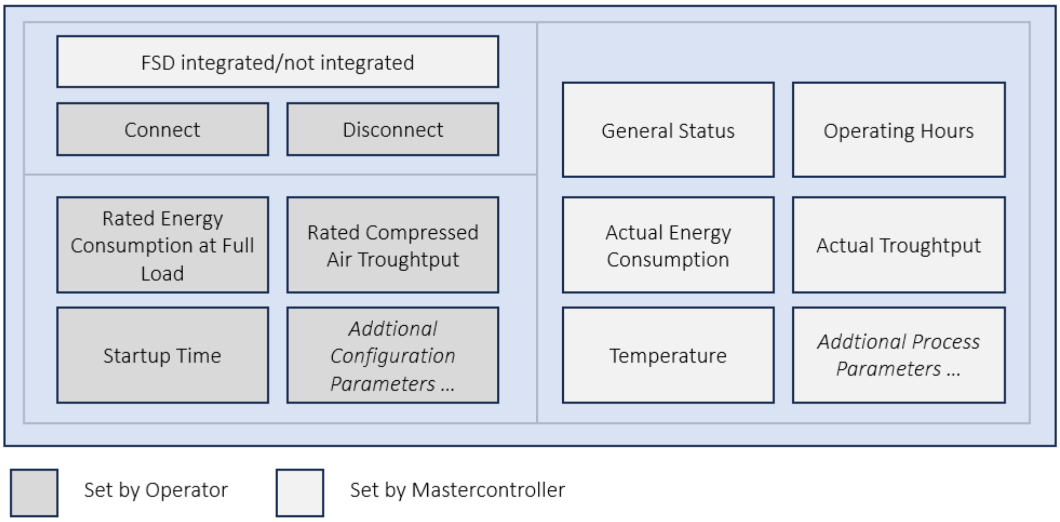

Figure 5: HMI of the FSD channels

What are the advantages of modularization through MTP?

Using the MTP standard offers the advantage of simple and fast software integration of a process-safe controller with the extensive user interface and the accessible channels for the FSD compressors at the process control level. Otherwise, the integration of an energy-efficient control system would involve considerable effort, which would otherwise not be required in many applications. The following advantages are associated with the use of a modular compressed air system:

Energy Saving

The influence of modularization on energy consumption is heavily dependent on the compressors used and the scale of the compressed air requirement. In principle, a large saving in energy consumption is always achieved if the idling of FSD compressors is prevented- i.e., if they do not have to regulate the operating pressure by means of two-point control. Also, a large VSD compressor that covers the entire compressed air demand comes with an exceedingly high purchase price. Therefore, a modular combination of both FSD and VSD compressors offers significant savings potential. When efficient FSD compressors are used in a network, this achieves a higher overall efficiency compared to a single, larger VSD compressor at a lower purchase cost. The modular concept also helps in avoiding oversizing of air compressor system which in return reduces energy consumption.

Redundancy and Failure Prevention

Sophisticated interfaces standardized by MTP enable the communication of diagnostic information in modular connections to detect faults at an early stage and take preventive measures. If an FSD compressor should nevertheless fail, this only leads to a temporary reduction in the maximum possible total capacity and has no impact on the stability of the compressed air supply. This setup provides redundancy, ensuring uninterrupted production. If one compressor shuts down, the other takes over to keep the operations running smoothly.

Quality assurance through diagnostics and maintenance

Inadequate maintenance can significantly impact energy consumption through reduced efficiency, air leaks or pressure fluctuations. It can also lead to high operating temperatures, poor humidity control and excessive contamination. Determining whether a system is well maintained and functioning properly requires regular measurement of the system's performance, pressure, flow, and temperature.

Incorporating compressed air quality monitoring instruments into the network makes it easier to provide high quality air. On the one hand, the compressed air quality parameters are published centrally in direct connection with the other process parameters in the OPC UA server, which enables more comprehensive and informative analyses. In addition, the control system can take FSD compressors out of operation if, for example, they are providing compressed air of too low a quality due to contamination or a defect. These mechanisms enable a high quality of compressed air in both the short and long term.

“Numbering up” instead of “scaling up”

It is not necessary to redesign the entire compressed air supply if the compressed air demand changes in the long term- instead, FSD compressors can be dynamically added to or removed from the network. As a result, in contrast to a rigid network of air compressors, no additional factors need to be considered in the initial design to meet future increases in demand- instead, additional FSD compressors are simply added to the network when the delivery capacity is expanded. This avoids oversized compressed air systems. An oversized compressor consumes more energy to generate the same amount of air flow compared with a properly sized compressor and therefore has larger annual operating costs.

Extended application options

From a certain plant size, the compressed air supply is decentralized to different stations to prevent oversized compressed air line systems. With very dynamic compressed air requirements at the stations, the disadvantage is that every individual station must be designed for the maximum compressed air requirement, even if this is only required for a brief time. The rapid integration and separation of FSD compressors makes it possible to redistribute them between the stations depending on changes in demand. This leads to considerable savings in procurement and maintenance costs.

Conclusion

By using a modular network of compressors, energy consumption and CO2 emissions can be significantly reduced. In addition, maintenance costs are reduced, as the given process parameters enable more sophisticated diagnostics and thus more predictive and targeted maintenance can be carried out. Modular compressors also increase process and quality reliability and avoid the use of oversized compressed air systems. The central control unit of the network can be integrated into existing structures via MTP with little effort.

In further work on modular compressed air systems, a concrete control strategy can be developed along with the user interface for MTP implementation.

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