Advantages of variable speed actuators

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Variable-speed drives (VSD) have increasingly become established in industrial plant engineering and even the consumer sector in recent years. In many cases, the reason for their selection can be found in total energy savings throughout service life. It is, for example, cheaper to have a variable-speed compressor supply precisely the flow of air required instead of running it at a fixed speed for maximum demand and generating the actual demand by means of throttles, and thus wasting energy. A further motivation frequently mentioned for the use of VSDs in industrial processes is the matching of actuator elements to diverse process requirements. Many of the advantages offered by VSDs in industrial applications can also be realized on the valve market and in electrical actuator drive systems, and new benefits are also being added. This overview article will: outline the structure and methods for "generation" of speed variation; explain the benefits using applications in the valve field; and indicate design and project-planning advantages arising from the use of VSDs.

Design of a variable-speed drive

There are different ways of running a motor with variable speeds. For mains voltages of less than 1000 V and outputs of several 100 kW, the so-called "frequency converter with DC voltage link" is used, mostly in combination with a robust induction motor. Therefore, only this version will be briefly outlined in the following.
A variable-speed drive (VSD) requires 3-ph voltage at the motor, changeable both in terms of frequency (speed) and amplitude (voltage level determines torque). However, the voltage provided by the mains supply is constant in terms of frequency and amplitude. The conversion takes place in two steps:

1. Rectifying and smoothing

The 1-ph or 3-ph feed voltage is first converted into a (ripple/wave-like?) DC voltage using a network of rectifier diodes ("bridge rectifiers") (Figure 1). The voltage is further smoothed via "thick / big" capacitors which are used as buffer for the energy.

2. Inversion

The second part of a frequency converter consists of six fast "electronic" switches connecting the DC voltage in a precisely defined rhythm to the three motor terminals. By switching very

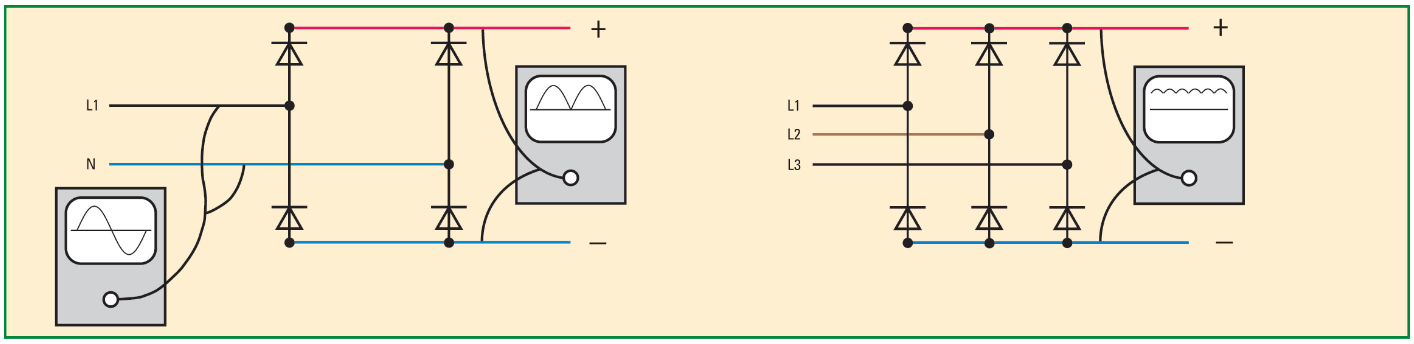

Fig. 1: Rectification of feed voltage

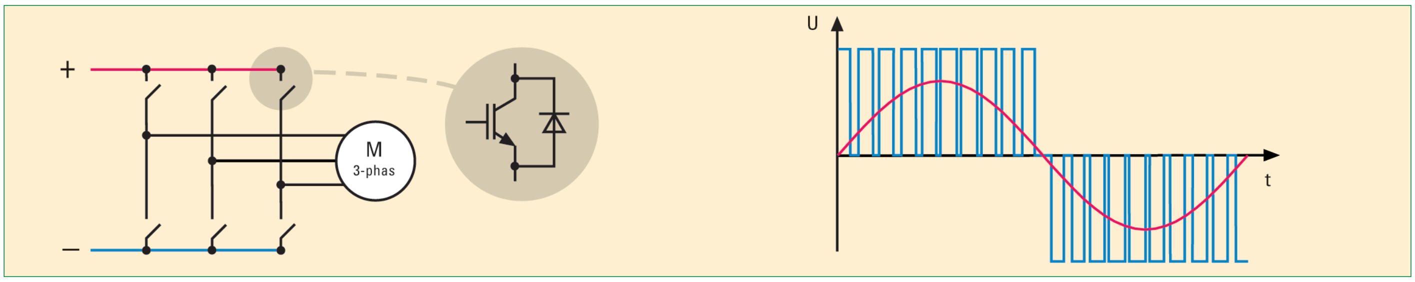

Fig. 2: Smoothing and pulse-width modulation

quickly and selecting the proper voltage (pulse-width modulation), a three-phase voltage system is established (Figure 2). The large amount of DC voltage "slices" are filtered by the motor windings, only the "basic oscillation" of the voltages generates a rotary field with the desired frequency and voltage amplitude. The "trick" is to extrapolate the voltage patterns and to rapidly implement the switching states. In modern VSDs this task is performed by high-speed processors (micro-processors or micro-controllers). The switching commands are implemented by electronic components which have been available as serial parts since the beginning of the 1990s and virtually meet the requirements of an "ideal switch", i.e. switching rapidly and without loss: "IGBTs" (isolated gate bipolar transistors). Just to give an idea of the capacity of these components: under normal conditions, each of the 6 IGBTs of an inverter typically switches voltages of about 540 V (three-phase link voltage for rectifying 400 V) on and off at a frequency of approx. 6,000 to 10,000 times per second.

Advantages of the use of variable-speed actuators in valve applications

1. Starting up - slowly but consistently

Valves in power plants (Figure 3) or water treatment plants sometimes have to resist major differential pressure. When operating the valve quickly over the entire travel, turbulences and vortices are created. As a consequence, stress is put on the material and this can represent a hazard for valve, pipe work and connection parts.

Fig. 3: Steam reducing valves with injection cooling operated with SIPOS 5 Flash variable speed actuator

Undesired or damaging side-effects such as cavitation and "water hammer" which spread within the entire plant can be prevented by a well-"controlled" operation speed of the flow restrictor.
When first opening the valve slowly, pressure compensation may take place; on reaching a defined valve position, the actuator may be operated at increased speed.
For variable-speed motors, the motor frequency is adapted by means of a so-called "ramp function generator" with defined acceleration and jolt limitation ("ramp").

2. Closed tightly without overtorque

If the actuator moves the valve at full speed into the valve seat, the function "close tightly" is fulfilled, but at the price of a high dynamic load torque for both valve and actuator. During the delay time between detection of the torque and switching-off, the motor continues its operation at full speed. Even after the motor has been switched off electrically, the stored kinetic energy continues to increase the excessive torque. Valve and actuator both have to be sized for these excessive torques - a real waste compared to normal operation! Additional brakes at the motor can be used to counter this effect. This creates additional costs and wear on the brakes.
An actuator with VSD can control the output speed and slow down before reaching the end position, so reducing the kinetic energy to a minor fraction. Furthermore, the setpoint of the motor voltage can be selected so that the desired stall torque corresponds to the tripping torque of the valve. Thus, even the delay time between detection of the cut-off and the actual motor OFF is irrelevant.
In an example using an actuator combined with a valve, this can be illustrated: With powerful torque, the actuator gently moves the valve out of one valve end position and into the other end position (Figure 4). The integral frequency converter automatically modulates both frequency and amplitude in the end positions. Consequently, the actuator is operated at reduced motor speed. I.e. the actuator is operated at reduced speed into the end position areas (which can be set in size at x % of the valve travel) - without excessive torque, even in the case of blockage. ▶

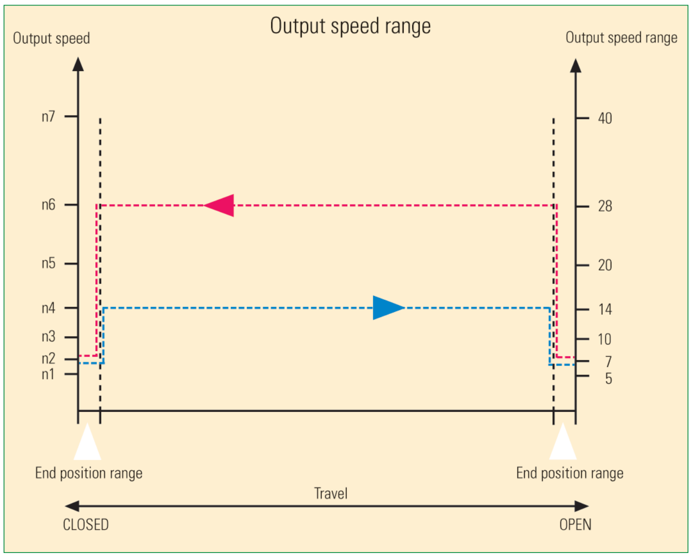

Fig. 4: Low-speed extension and movement to end position

Fig. 5: DN 1800, PN 1.6 butterfly valves with variable speed actuator for control of air feed in a steel plant furnace

Fig. 7: Variable speed actuator system on a decanter in a sewage treatment plant

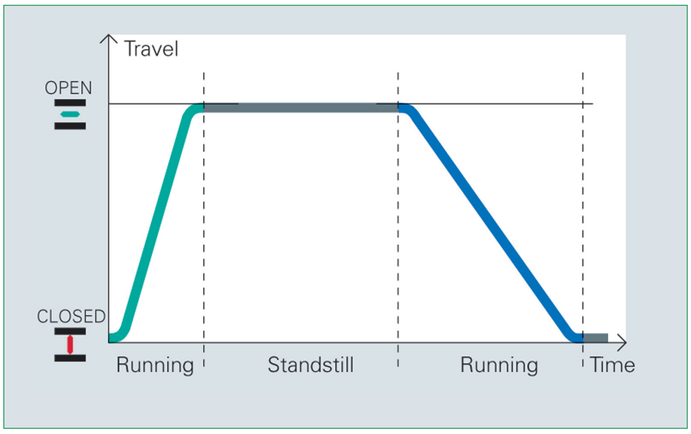

Fig. 6: Different speeds for OPEN/CLOSE direction can be selected and programmed from seven available speeds

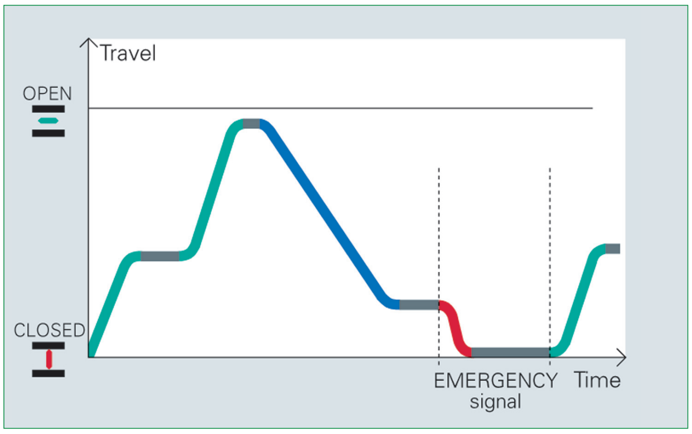

Fig. 8: Further speeds can be parametered for EMERGENCY OPEN/CLOSE direction operation, in addition to the adaptable speeds for opening and closing

Thus valve, valve seat, sealings, and other mechanical components are treated with special care (Figure 5).

3. Different speeds over the travel

Sometimes, it may be reasonable to operate the actuator at different speeds in different sections of the valve stroke, e.g. to by-pass critical positions within the process without stimulation by resonances or to keep the process variables pressure, temperature, flow etc. at a fixed level or to linearise the valve characteristics. What can only be achieved via switching on/ off cycles (stepping mode) for "fixed-speed actuators" and with many small impulses (and many start-up current spikes), is the standard for the VSD actuator. There are different options for changing the output speed during operation:

4. Using different positioning speeds for OPEN and CLOSE direction

The variable-speed actuator can be set/ programmed so that the positioning speed of the valve (resp. equipment) in direction CLOSE differs from the speed in direction OPEN (Figure 6). A typical application is a "decanter" used in sewage treatment plants with SBR procedure (Sequencing Batch Reactor) (Figure 7). The decant arm is lowered into the medium at low speed to avoid swirls in the activated sludge basin. After the water has run off, the decant arm lifts at higher speed from the wastewater surface and returns to the initial position to allow fast filling of the basin for the next batch process.

5. Different output speeds for normal operation and emergency situations

Control engineers know this dilemma: when having to select the optimum sizing of a closed-loop control for both reference value and variable disturbance. It would be desirable if the "motor operated valve" (MOV) was positioned precisely during modulating duty at low output speed, but moved at maximum speed to a predefined position in case of an emergency situation (load shedding in a power plant,...). When using variable-speed actuators, this can easily be done (Figure 8). How both the position and the behavior can be pre-defined only depends on the so-called "intelligence" of the program.

The function in case of an EMERGENCY input signal (ESD - emergency shut-down) can be as follows:

For VSD actuators, different speeds (e.g. faster ones) can be set for both directions via the emergency input.

If the emergency signal is present, the actuator is operated at the set speed into the predefined emergency position (CLOSED, OPEN, or any intermediate position). In addition, different software versions based on the customer requirements are available. ▶

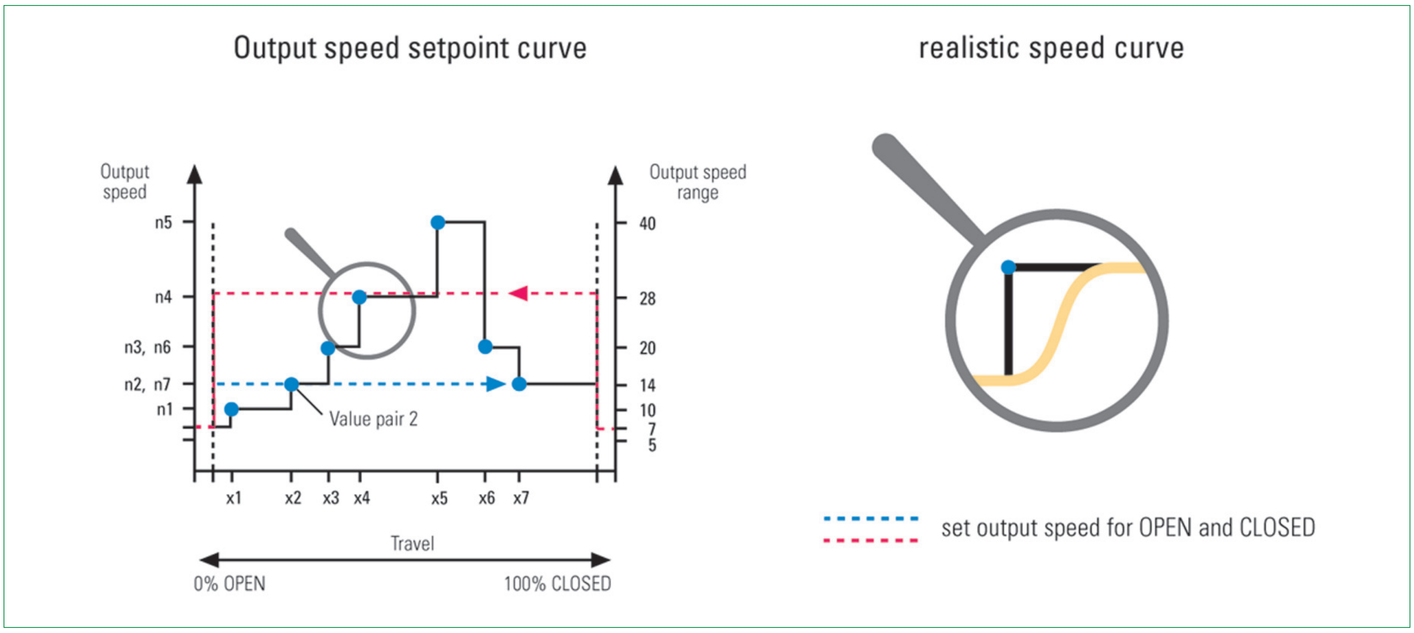

Fig. 9: Stroke-speed curve

Fig. 10: SIPOS 5 Flash in a district heating pumping station

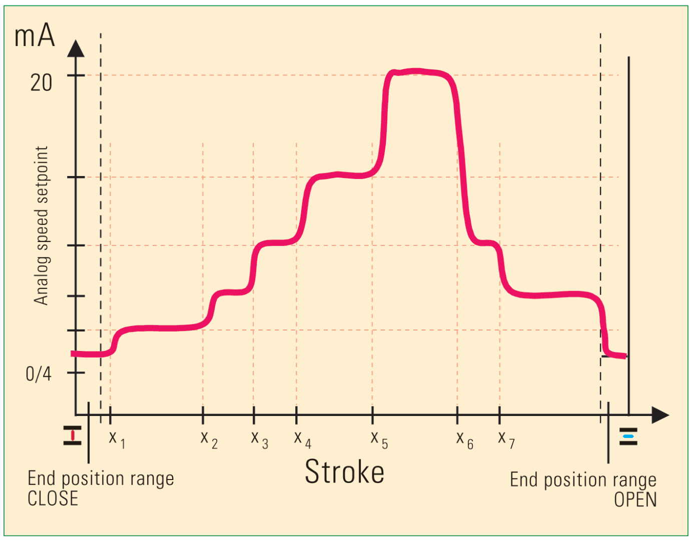

Fig. 11: Analog speed setpoint

6. Travel-dependent speed variations

For VSD actuators, the output speed or positioning speed of the actuator can also be set (i.e. programmed) differently across the travel. The entire travel of the valve can be divided into up to ten different travel sections with different speeds (Figure 9). By means of this function, a proportionality of travel and flow rate can be reached. The variable-speed actuator achieves this by changing the output speed while running from OPEN to CLOSED and vice versa. The EMERGENCY function is not affected. It can also be distinguished whether the actuator is to follow this characteristic, which has been defined via interpolation points, for local control, remote control, or both.

This function, for example, is used in a variety of district heating plants in Sweden (Birka district heating, Stockholm; Fortum district heating, Upplands Väsby-Akalla). The actuator operates the valves at the 120°C/ 60 °C water distribution (Figure 10). The actuator passes the first section of the travel at high speed, until the pressure drop on the other side of the valve is achieved; the actuator is then operated at reduced speed to end position CLOSED. The same happens for the opposite direction. This procedure successfully avoids water hammer within the pipework.

7. Analog speed setpoint

For actuators controlled via frequency converters, a process-oriented speed setpoint by means of an analog 0/4 - 20 mA signal for the speed curve (Figure 11) is also possible. Via the "analog speed setpoint" function, the actuator can operate at different speeds without reprogramming during operation.

Advantages of the use of variable-speed actuators during planning and sizing

1. Compensation of voltage fluctuation

For an asynchronous 3-ph AC motor, the output speed changes almost proportionally to the square of the connected motor voltage. At 70 % of the nominal voltage, the conventionally controlled actuator provides only about 50 % of the torque which would be otherwise available. Even if the voltage fluctuations in the standard mains are not that significant, the local voltage in the most powerful industrial mains will collapse if neighboring large-scale consumers (pumps, compressors, large motors) start up. The actuator must be designed for this low voltage situation. On the other hand, it must be ensured that the valve is not damaged in presence of maximum voltages (including excessive voltage within the permissible tolerance). The valve must also be sized for this kind of operation.
With a VSD actuator, the output voltage and thus the torque is for a major part independent of the actually present mains voltage - a sizing asset which may easily reach the factor 2!

2. Single-phase at full torque from standstill - and, if necessary, with inverter

Occasionally there is a requirement that the actuators must be operable in case of power failure - by means of a battery-supplied inverter. The use of a "standard" 3-ph AC actuator is not cost-effective due to the high cost of a three-phase inverter - they are not available as standard devices. Single phase inverters, however, require single phase AC motors, i.e. "universal motors" equipped with starting capacitors whose problem is the starting torque.
The variable-speed motor can convert a single-phase feed voltage into a variable three-phase voltage for the motor - within the output limits set by the manufacturer - and therefore provide this special function without any additional efforts or performance losses.

3. Terminal design

With a frequency converter, the motor no longer has to start from slip = 1 (output speed = 0) up to the nominal slip with a high starting current: a new frequency is defined every second and the motor is continuously operated at the current nominal position. In other words: the starting current is less than or equal to the nominal current.
When using several actuators at one terminal block, the control cabinet volume and the cable cross sections can considerably be reduced!

4. Automatic phase correction

For the inverter it does not matter in which sequence the phases are connected (remember: the voltage is rectified anyway) - thus an automatic phase correction is always present. The direction of rotation of the motor is exclusively determined by the specification in the inverter.

5. Starting torque

For low frequencies, the voltage amplitude enables fine adjustment of the motor torque. Since in particular sufficient voltage reserve for low frequencies exist, the starting torque can be selected so that starting is possible even if the valve is warped.

6. Motor monitoring -full motor protection integrated

Apart from the continuous measurement of the motor temperature via sensors, the frequency converter also controls the motor current (measured within the DC voltage link). The "burned motor" phenomenon has become obsolete.

7. Spare part storage and planning (output speed/ torque/ direction of rotation)

The option of freely setting the output speeds and tripping torques within wide limits, or of inverting the direction of rotation considerably facilitates planning and process optimisation during operation of the plant.
The motor versions and the actuator types and sizes used within a power plant/ industrial plant are heavily reduced due to the programming possibilities of the VSD actuators.
The reduction gearings which would otherwise be used and different motors for different output speeds are no longer required. This leads to a considerable decrease of the number of spare parts on stock. ■

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