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Energy and cost saving by retrofitting of frequency converter for motors "increased safety"

A basic requirement for an effective production and a high, constant product quality in chemical and petrochemical industry is the exact proportioning and control of the quantities of the media which are directly and indirectly involved in the process, e.g. reaction partners, heat exchanger flowrate for cooling and heating of the reaction vessels, etc.

For the pumping of these media, usually pumps or fans are used. When these devices are driven by means of an asynchronous machine which is directly operated on the mains supply, the flow rate of the pump can be set by an adjustment mechanism between motor and pump or by by-pass valves and/or flow reduction valves. Due to the high purchasing costs and the maintenance effort involved, the use of adjustment mechanisms is limited to only a few fields of application.

Adjustment of the flow rate by a flow reduction valve

A basic disadvantage of the use of bypass and flow reduction valves is the fact that - depending on the flow rate adjusted - very high hydraulic power losses occur on the valves which cause a strong decrease in the efficiency of the system.

A possible configuration for flow rate adjustment by means of bypass and flow reduction valves is shown in Figure 1.

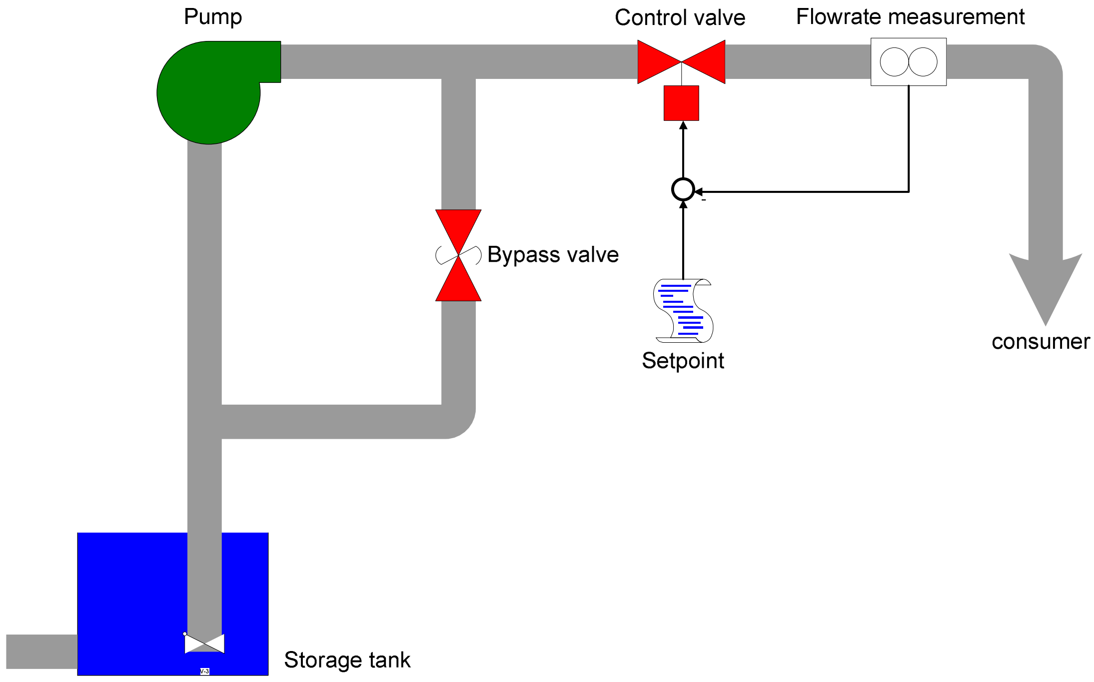

Figure 1: Adjustment of the flow rate by means of a flow reduction valve

On principle, this construction is also used in heating installations, whereby the flow reduction valve is replaced by the thermostatic valves in the rooms. The bypass valve then serves to limit the pressure difference in the heating system and to avoid disturbing whistling noises in the thermostatic valves. In ventilation systems, throttle flaps are also very often used to adjust the air quantity. /2/, /3/

Based on the arrangement shown in Figure 1, an analysis of the losses occurring in the individual parts of the system was performed for partial load operation with 60% of the rated flow rate. Striking - and finally responsible for the bad total efficiency of the system - are the high losses in the flow reduction valve and in the bypass valve. The bad efficiency is not, however, the only disadvantage of this type of flow rate adjustment: Especially when abrasive media are pumped - as it is, for example, the case in the colour industry for pigment suspensions - high abrasion occurs on the valves.

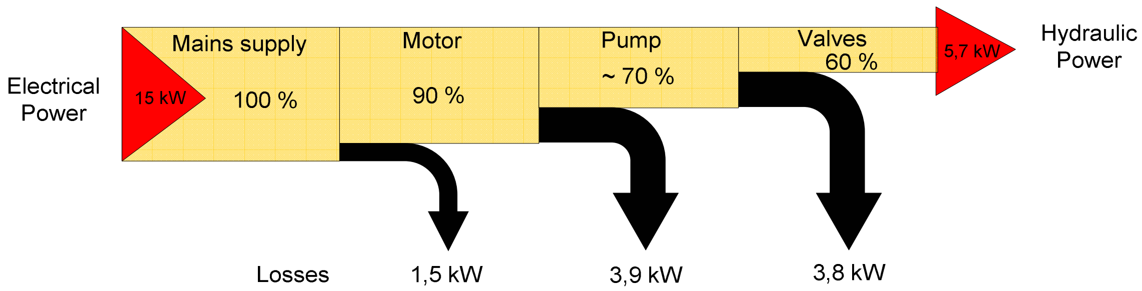

Figure 2: Sources of the losses in the flow rate adjustment at 30 m³/h by means of a flow reduction valve, design flow rate: 50 m³/h

Adjustment of the flow rate by means of a frequency converter

The energetically much better method for flow rate adaptation of pumps and fans is performed via speed adjustment of the driving motor. Here, flow reduction valves and bypass valves can be dispensed with and the pump delivers only the liquid quantity required in the production process at the current moment. In the case of the asynchronous machines normally used today, an economic speed adjustment is possible only via a change of the supply frequency, usually with proportional adjustment of the machine supply. Due to the great technological progress achieved in power electronics and microelectronics, very compact and reasonably priced frequency converters are available on the market today. Here, in contrast to other applications - as, for example, in the case of positioning drives - the dynamics must meet only very low requirements so that it is completely sufficient to use a frequency converter with simple U/f control. Figure 3 shows the block diagram of a facility for the conveyance of liquids by means of a speed-controlled pump. As a result of the principle, loss sources in the components "flow reduction valve“ and "control valve“

cease to exist; it can, however, be observed that the efficiencies of the pump and of the driving motor are getting slightly worse.

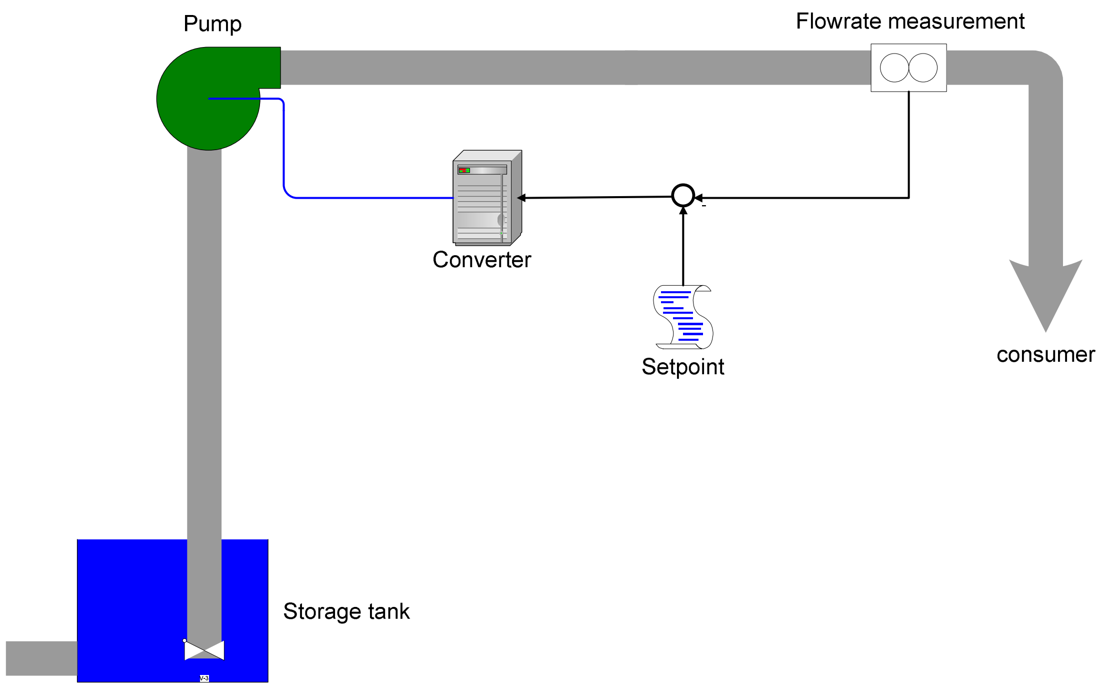

Figure 3: Adjustment of the flow rate by means of a frequency converter

Under energetic aspects, the focal points of the loss generation have changed in the arrangement shown on Figure 3, whereas the total system efficiency in the partial load range has clearly increased (as can be seen in Figure 4).
The cause of the efficiency decline of the pump is that it is no longer operated in its designed speed range and shows, therefore, worse hydraulic properties. In the case of the machine, additional losses occur due to the harmonics contained in the converter output voltage. Compared to the fundamental mode losses during rated operation, these losses are, however, small. Globally contemplated it must also be taken into account that the total power delivered to the pump cubically decreases with the speed so that the efficiencies of the motor and of the pump, which are getting worse with decreasing speed and compared to mains operation, do not lead to an increase in the power loss of these two components, but - absolutely contemplated - to a drastic decrease in the power loss. However, when the flow rate is adjusted by means of a frequency converter, the frequency converter itself must be considered as an additional loss source. Due to the high efficiency (usually between 0.96 and 0.98), the additional losses of the converter can be regarded as very low - compared to the losses saved due to the omission of the flow reduction valve.

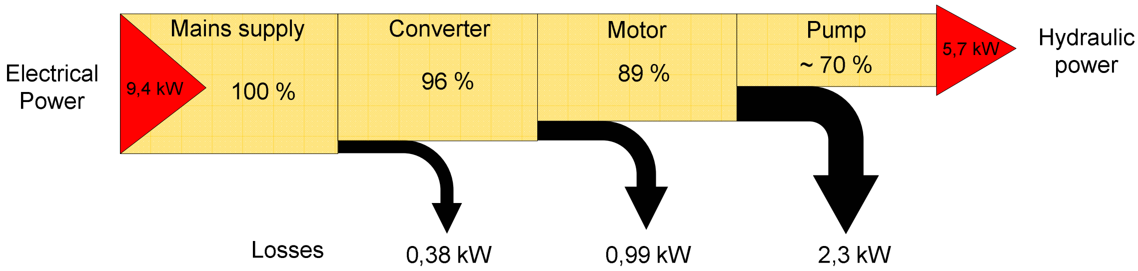

Figure 4: Loss sources during output adjustment of a pump by means of a frequency converter. Adjusted flow rate 30 m³/h, rated flow rate: 50 m³/h

Another advantage which arises when the pump motor is supplied by the frequency converter is that the electricity network is protected against voltage drops when the pump is switched on. This becomes increasingly important in the case of high-performance pumps. Moreover, no pressure surges occur in the connected pipelines and fittings when the pump speed is slowly increased. As flow reduction valves and control valves are not used, the sources of possible leakages can also be left out of account - a fact that increases the safety of the facility when substances with a risk potential are pumped.

Costs of frequency converter retrofitting

When newly installed facilities are equipped with a frequency-converter-fed motor, first of all the costs of the frequency converter must be mentioned. As initially explained, the pump drive does not make high demands on the motor as far as the dynamics or the positioning accuracy are concerned, so that it is sufficient to use a frequency converter of a simple design for this driving task. For the motor described in Figure 4 (18 kW rated power), a frequency converter in accordance with the manufacturer information would be available from approx. 2000 €. Additional costs would arise for the assembly and placing into operation, the possible connection to the process control system and the possibly required switchboard. To simplify matters, only the converter purchasing costs have been considered in the following. Up to now, it has been indispensable for the type of protection "increased safety" to test the motor together with the frequency converter and to specify the frequency converter type in the EC type-examination certificate of the motor. This considerably increased the test effort, and the later failure of a component frequently made the exchange of the complete driving system necessary if the same type of the respective component was no longer available.
When the new certification concept for motors of the type of protection "increased safety", which is described in the following, is applied to the frequency converter, only slightly higher costs (compared to the mains-operated machine) have to be expected for the motor, and exchange of a component at a later date will be possible without any problems.

Amortisation of the use of a frequency converter

For the person responsible for the planning of a new facility, the additional costs, the amortisation time, possible follow-up costs as well as the influences on the mode of operation of the facility are decisive factors when the decision for or against the use of a frequency converter is to be made.
For a rough determination of the amortisation time, above all the energy costs per kWh, the load profile with which the motor will later be operated, the complete annual operation time, other potential influences on the production process as well as the costs for the frequency converter are important factors.
For the example used in this lecture, additional costs for the frequency converter of € 2000,- are assumed. For a motor of the type of protection "increased safety", the same costs as for a mains-operated motor can in a first approximation be estimated. In addition, a PTC thermistor evaluation unit - whose function has been tested in accordance with Directive 94/9/EC - is required, whereas the motor protection switch, which is required for mains-operation, is not necessary.
As to the energy costs, an energy price of 0.194 € / kWh is assumed for the example described here. This is the energy price which many energy suppliers presently charge their business clients. For industrial clients, who sometimes also operate power plants of their own, the energy costs are clearly lower, which is reflected in a prolongation of the amortisation times for the use of the frequency converter.
For a realistic estimation of the amortisation times, several load profiles were - as shown in Figure 5 - first of all defined. Thereby, the share of the rates of utilization in the complete annual operation time of 5000 h has been varied in three examples.

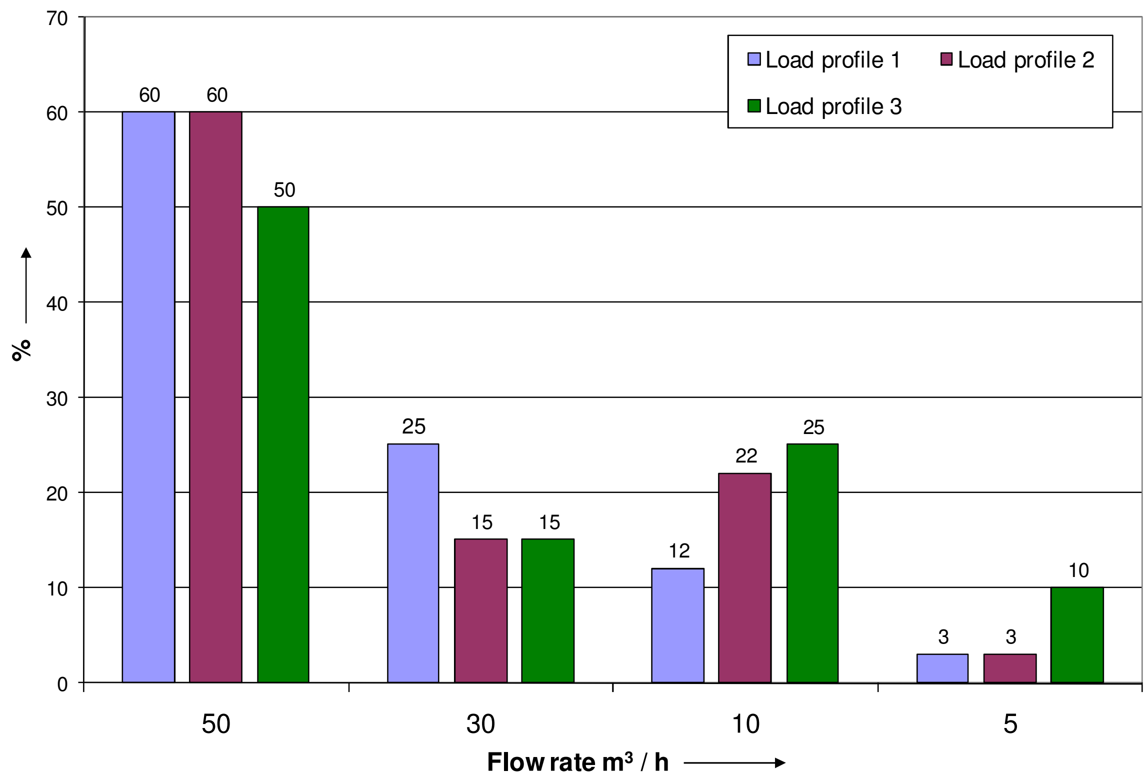

Figure 5: Assumed load profiles for the calculation of the amortisation times.

On the basis of the load profiles shown in Figure 5, the energy costs to be expected for mains operation and operation on the frequency converter can now be plotted against the different load profiles.

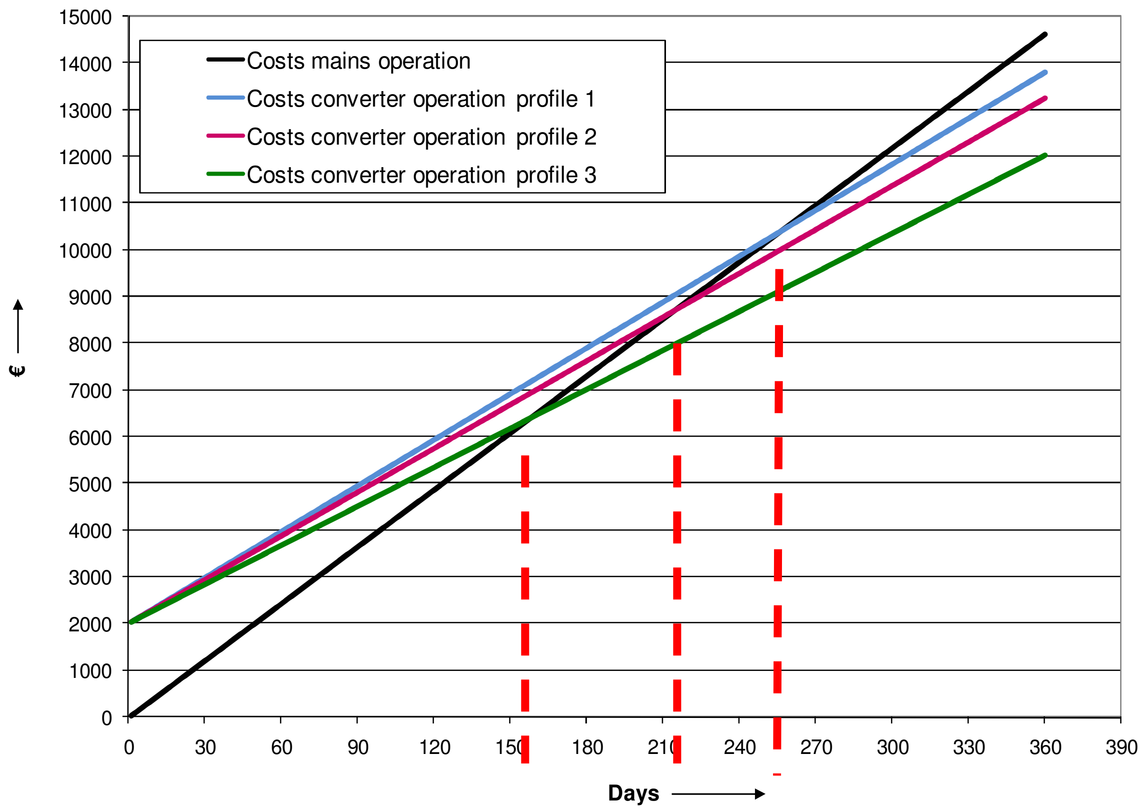

Figure 6: Development of the energy costs in the course of time for mains operation and for frequency converter operation. Purchasing costs of the frequency converter: € 2000,-

The costs of € 2000 - which have already arisen at the time t=0 for the converter-fed motors - are in compliance with the purchase costs of the frequency converters. From the intersection points of the curves for converter operation and mains operation directly result the amortisation times in days, as indicated by the broken lines.
Via the relation represented in Figure 6, the amortisation times can be determined for any investment costs (parallel displacement of the "converter curves“) and for other methods for conventional flow rate adjustment (flattening of the "mains curve“) than those shown in Figure 1, which are possibly more favourable under energetic aspects.
But even in the case of a clear prolongation of the amortisation times, the use of frequency converters for the motors of pumps and fans are in most cases - in view of the service life of the device - associated with large financial savings.
If a constant efficiency is assumed for the example described here, the amortisation times shown in Figure 7 are obtained in operating hours as a function of the output related to the design output of the pump.

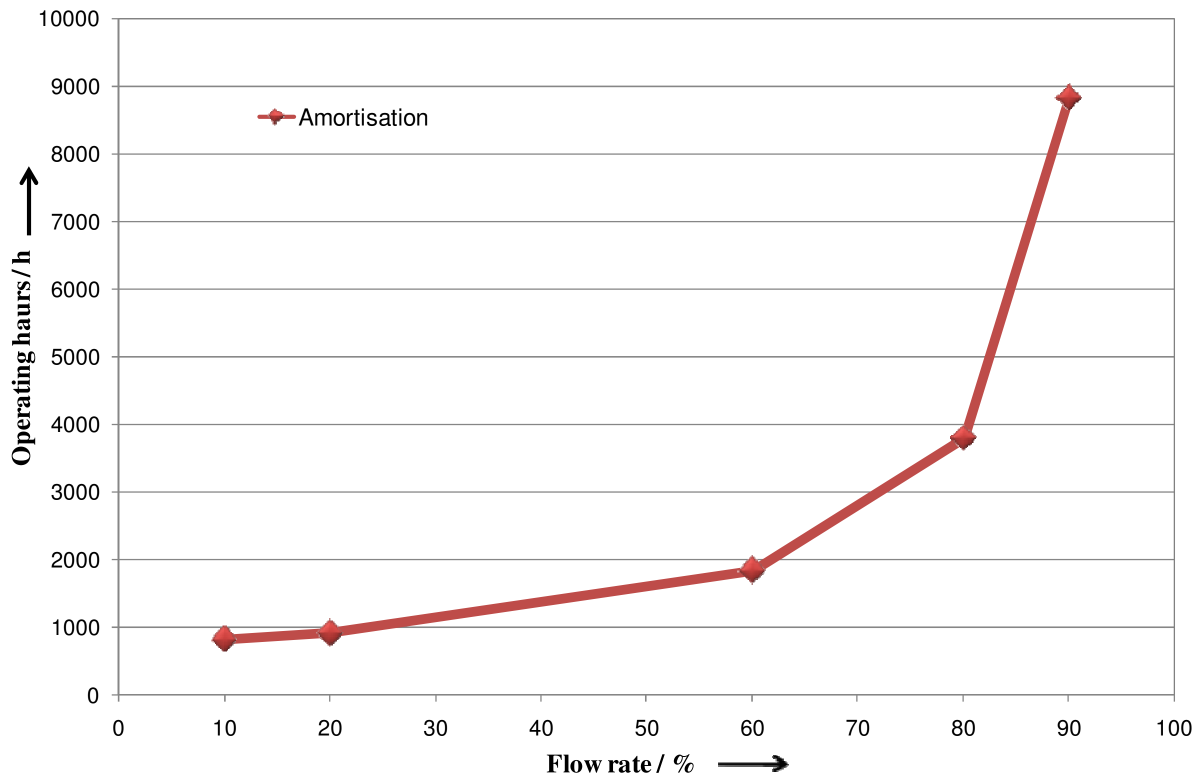

Figure 7: Amortisation time of the frequency converter as a function of the flow rate in percent related to the design flow rate of the pump

Figure 7 shows very impressively that the use of frequency converters is, above all, profitable when the pump must provide - frequently and for longer periods of time - clearly lower flow rate than its rated flow rate.

Backlog demand

In view of the share that motors used in potentially explosive atmospheres have in the chemical and petrochemical industry, it can be said that in the existing facilities, the share of frequency-converter-fed motors in the total number of the motors is clearly smaller than in the case of new facilities - a fact that is not astonishing. This, however, also illustrates that just the retrofitting of existing facilities with frequency converters includes - globally contemplated - still very large energy saving potentials. As an example, Figure 8 shows the distribution between mains-operated and converted-fed motors in a large German chemicals company /6/. The data are from 2006 and can approximately be transmitted also to other chemical and petrochemical companies.

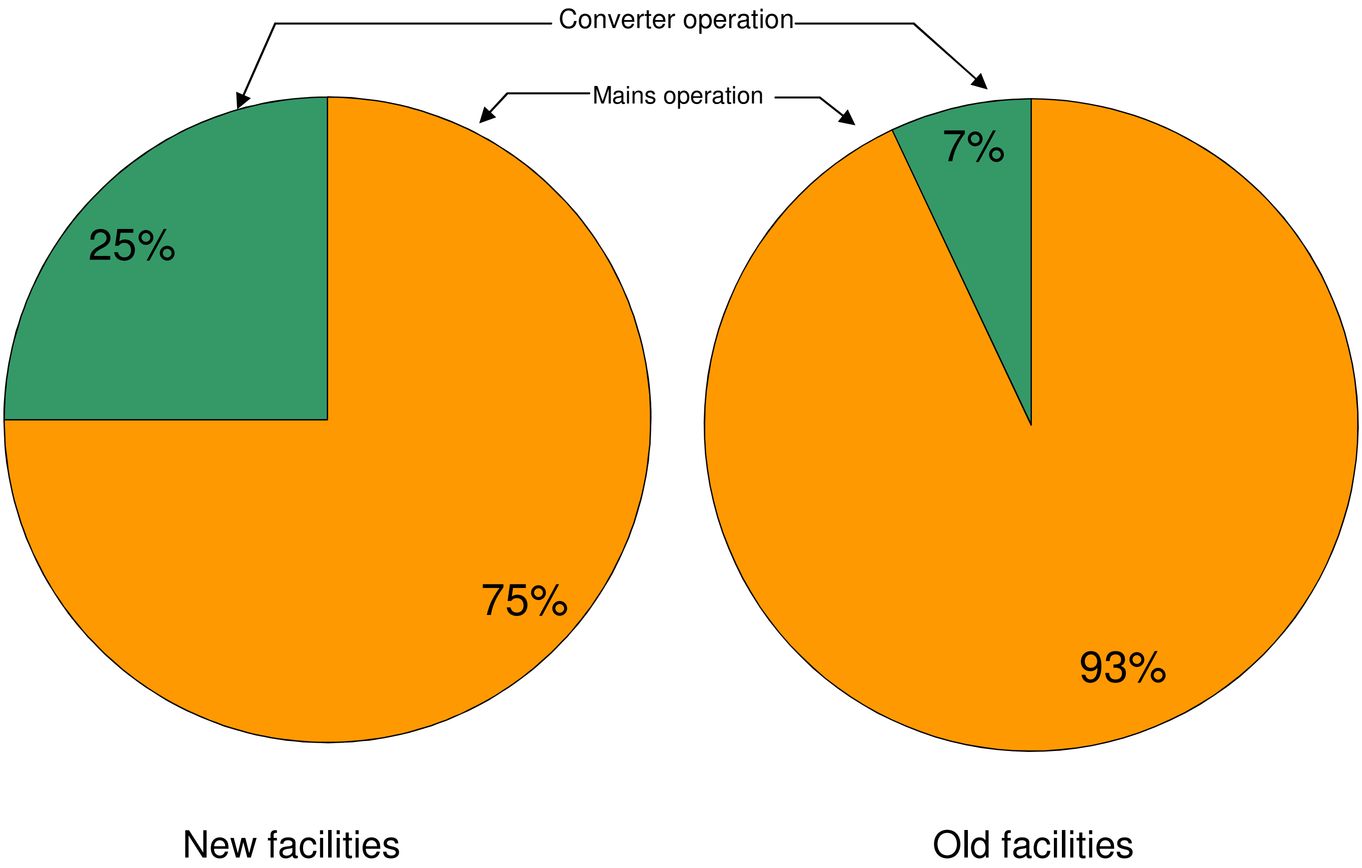

Figure 8: Share of converter-fed drives/motors in the chemical industry

Safe operation of frequency-converter-fed motors of the type of protection "increased safety“

In the case of the type of protection "increased safety“, explosion protection of the equipment consists in avoiding an ignition of potentially explosive atmosphere, whereupon the explosive atmosphere can also penetrate in the interior of the equipment, Figure 9

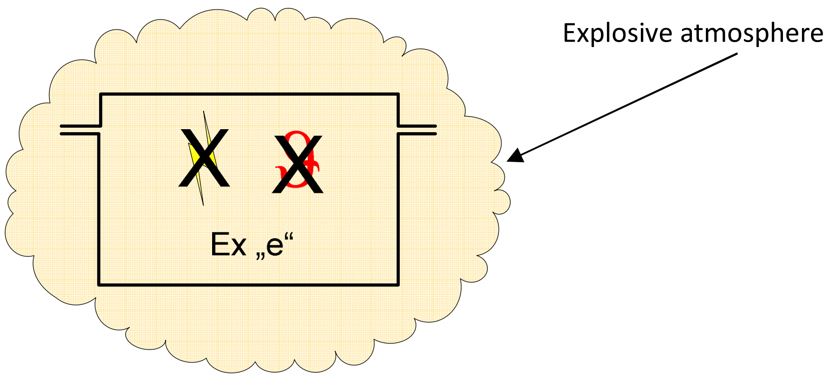

Figure 9: The principle of the type of protection "e“

In the case of an asynchronous motor, the possible ignition sources are hot surfaces, mechanically generated friction and impinge sparks and electrical discharges. /7/
For their avoidance, increased demands are made on the mechanical construction and design of explosion-protected motors, the electrical insulation system and the protection against inadmissible heating. Compared to mains operation, additional "risk factors" besides the ignition sources "electrical discharges“ and "hot surfaces" must be allowed for when frequency-converter-fed machines are used. These risk factors must be taken into account in the design of the machine and in the certification.

Electrical discharges

As a result of the fast switching processes of the power transistors and, thus, the high voltage increase velocities, travelling wave processes are formed on the cable to the motor, whereupon the input impedances of the motor and the converter, which are effective for the high-frequency processes, differ from the wave resistance of the cable. Generally, $Z_{motor} >> Z_{cable}$ is valid, so that a reflection factor close to 1 is obtained for the voltage wave running in the direction of the motor and the wave is reflected, Figure 10. In the case of the electrical cables, which are long in relation to the frequency of these wavelength processes, transient voltage peaks of up to twice the DC link voltage may occur on the motor terminals. The air gaps in the terminal box of the machine must be dimensioned to the transients, whereas the creepage distances must - according to EN 60079-7 - be designed only for the effective value of the converter output voltage. According to EN 60079-7, temporary voltage peaks do no lead to the formation of erosions by creepage currents on the surface.
It is, however, very important that the insulation of the winding is designed for these high voltage impulses with fast rising voltage. The winding insulation in the entrance area of the winding is also strongly stressed, as here a large part of the voltage drops. Partial discharges occurring here lead - over a longer period of time - to a destruction of the organic insulation of the enamelled wire and, finally, to an ignition-capable flashover and failure of the motor. If the manufacturer of the motor cannot guarantee freedom from partial discharges, a filter must be connected upstream to reduce the voltage load of the winding. /1/

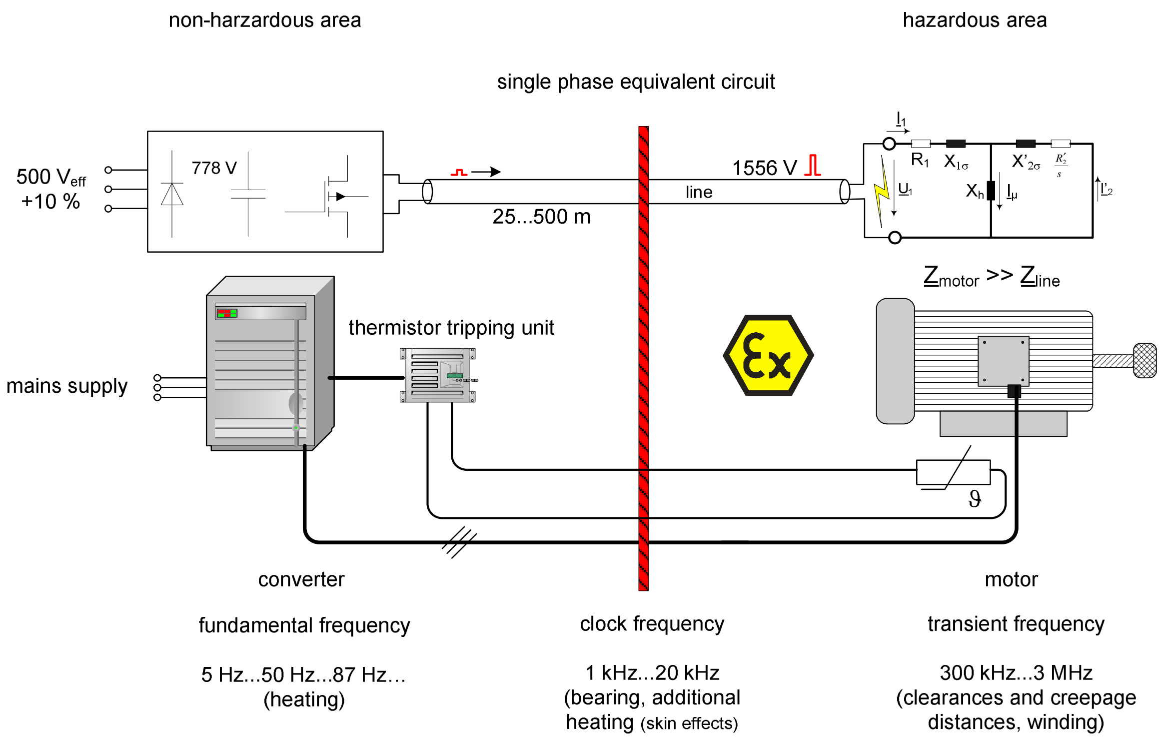

Figure 10: Development of transients on a frequency-converter-fed motor

Hot surfaces

If an electrical machine adopts an inadmissible temperature, the causes are too high a power loss inside the machine, e.g. by overload, or an insufficient cooling effect. An inadmissibly high power loss - especially in the rotor of the machine - may also be caused by an operation not in compliance with the specifications of the motor, e.g. with undervoltage.

These effects must be mastered - and ignition risks ruled out - by protective technical devices and operating parameters which are specified in the EC type-examination certificate. In addition to the limitation defined by the temperature class, the temperatures of the winding insulation during continuous operation, of the sealing devices and of other attachment parts must not be exceeded, in order to avoid premature aging with possibly ignition-capable failure.

In the case of the DC link converters normally used today, additional heating of the motor by harmonics is very low even when no sinusoidal output filter is used and lies - for the motors investigated at PTB - in all cases below 10 K. When the converter is designed in accordance with the specifications given in the EC type-examination certificate of the motor, the disturbance case "blocked motor“ need not be taken into account. As a result, the provided temperature reserve can be considerably decreased. A very important point, however, is the thermal resistance to the environment which increases with decreasing speed when self-ventilated machines are used. In Figure 11, this relation is represented for two machines of the sizes 180 and 132.

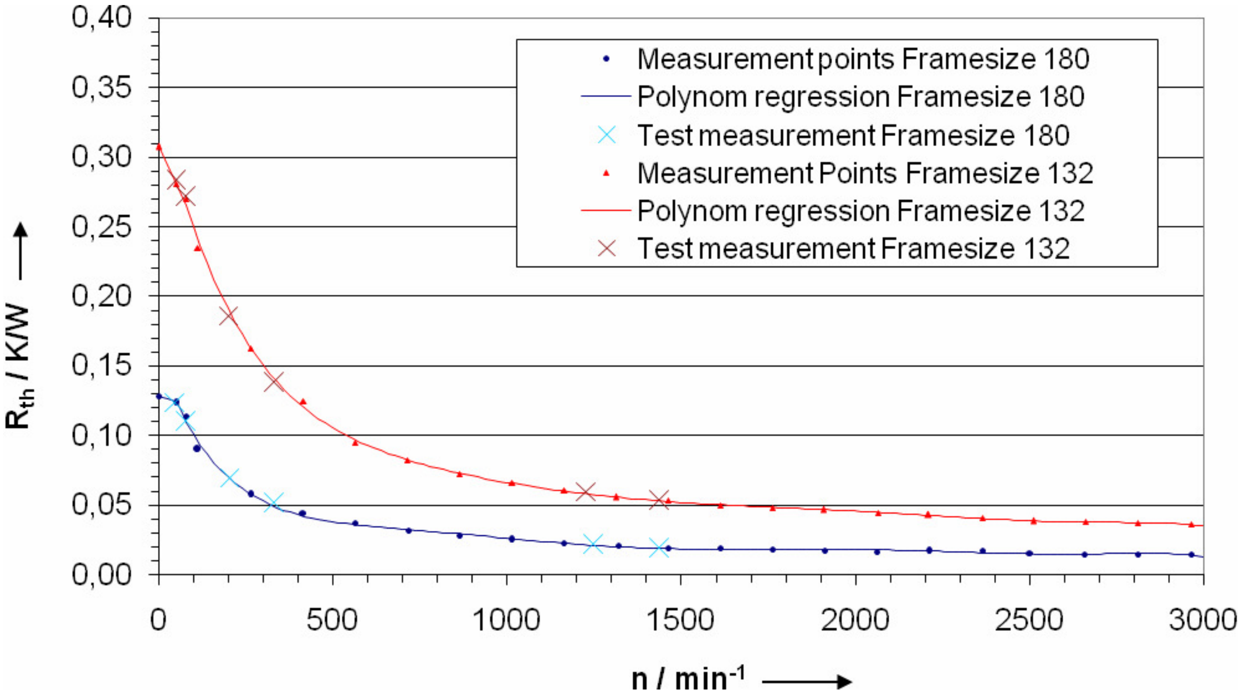

Figure 11: Development of the thermal resistance to the environment as a function of the speed

In the new testing and certification concept for frequency-converter-fed motors of the type of protection "e“, this effect is taken into account for a speed-variable current limitation of the frequency converters. As an example, Figure 12 shows the maximum machine current in relation to the rated current for a machine of the size 132. All operating points below the curve are permanently admissible; the points above the line are, however, admissible only for a limited time which has been calculated as a function of the overload. In the case of a machine current larger than 1.5 times the rated current, immediate switch-off takes place. /4/, /5/

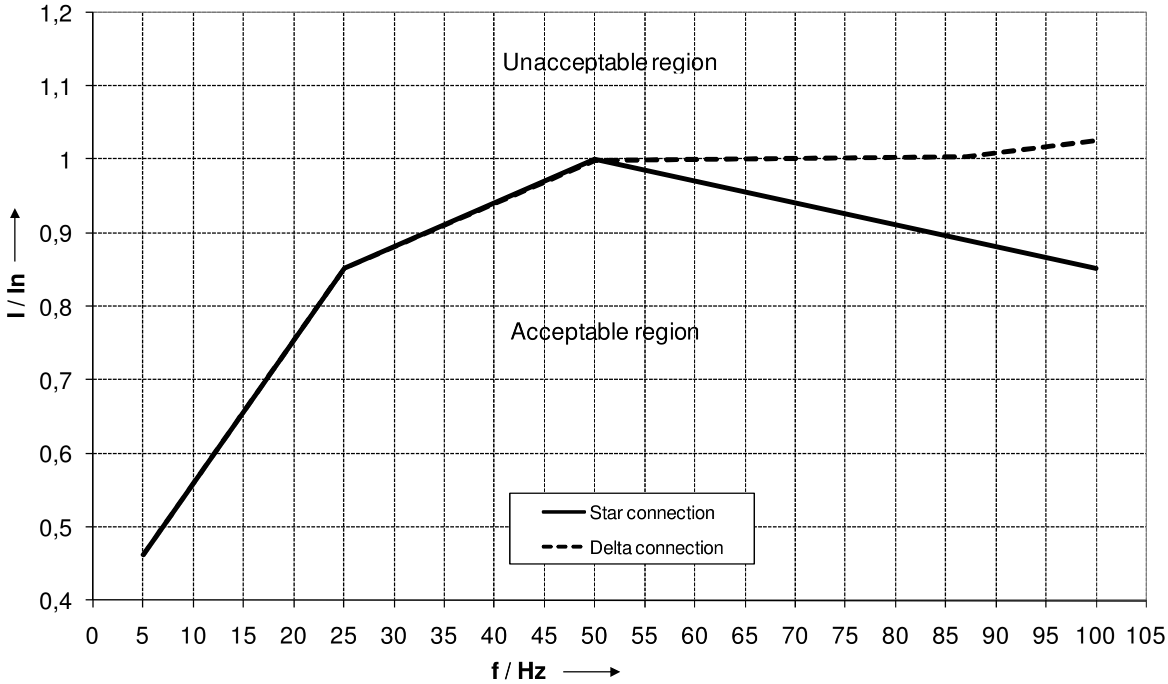

Figure 12: Speed-variable current limitation, from the EC type-examination certificate

The reference points of the curves were determined by measurements at PTB. In addition to this protection via a frequency-dependent current supervision, a second protective device, which has been certified in accordance with Directive 94/9/EC as a supervision unit, is required, as the frequency converter will not be certified (this is not desired by the manufacturer). Normally, this protective device is a direct temperature monitoring unit via triple PTC thermistor detectors with certified PTC thermistor evaluation unit. Direct temperature monitoring has the additional advantage that other disturbances, such as a blocked fan guard or too high an ambient temperature, are also detected.

Also very important for a safe operation is compliance with the operating parameters specified in the data sheet of the motor. Here, the fundamental mode on the motor terminals is of particular importance. If the voltage drop on the converter and on the motor connection cables is, for example, not sufficiently taken into account, the slip of the motor increases with the torque unchanged, and a strong temperature rise occurs, especially in the rotor. The voltage drop must also always be taken into account when a sinusoidal output filter is interconnected between the motor and the converter to reduce overvoltages. Figure 13 illustrates the situation:

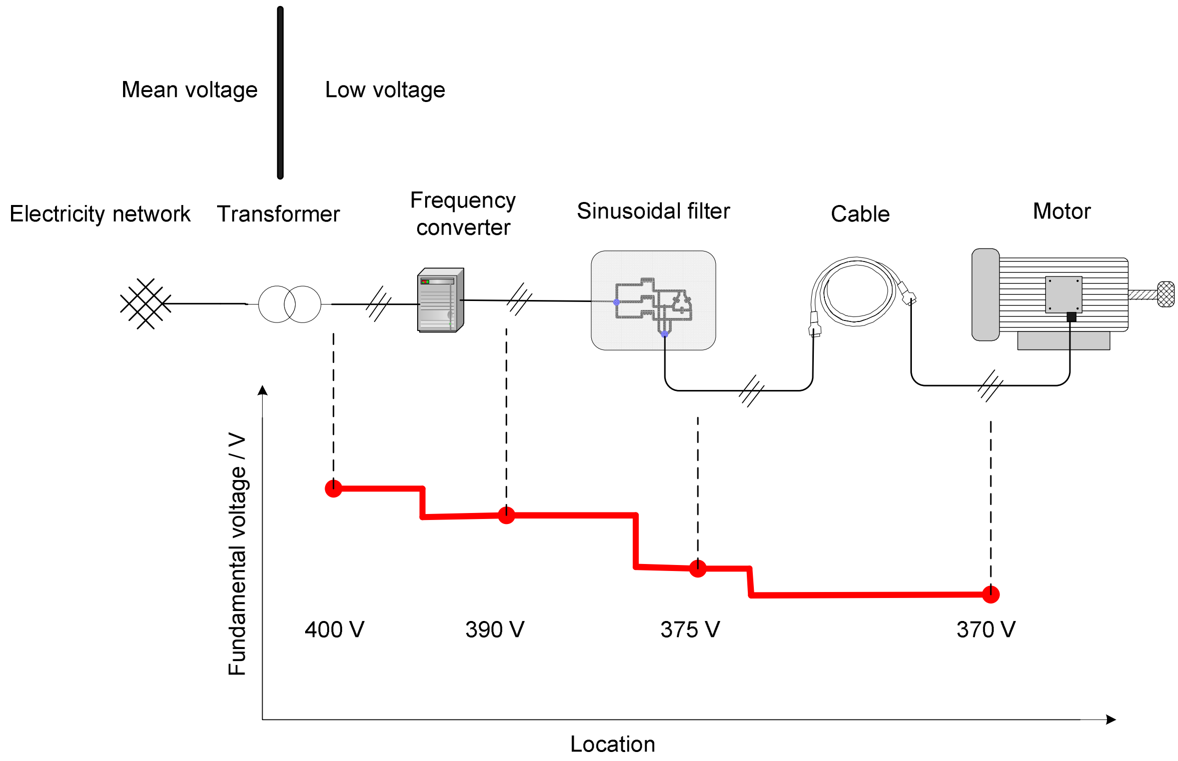

Figure 13: Voltage drops between electricity network and machine

Summary and outlook

The experience made so far with the new testing and certification concept for frequency-converter-fed motors of the type of protection "increased safety" is extremely promising, and it turned out that a certification for operation on the converter is possible without any problems up to temperature class "T3“. The prerequisite for a safe operation, however, is that the operating parameters of the motor specified in the data sheet are complied with and that the winding is suited for the occurring voltage impulses.
The new testing and certification concept for frequency-converter-fed motors developed at PTB has clearly increased the attractiveness of their use in potentially explosive atmospheres and opens up large energy saving potentials. As coupling of the converter to the motor is now no longer necessary for the type of protection "increased safety", the costs of the motor have been considerably reduced while a flexibility almost identical to that of a "flameproof enclosure" has been achieved.

At present, a motor protection device for frequency-converter-fed motors is being developed in cooperation with a company. The device will also allow frequency converters without speed-variable current limitation to be used, and the PTC thermistor is no longer mandatory either. Figure 14 shows the use of the protective device.

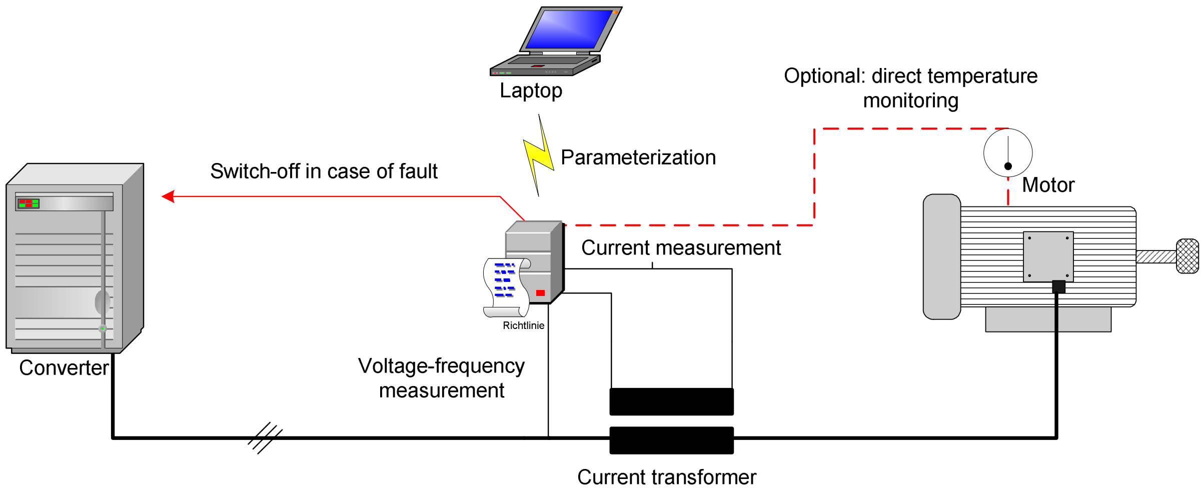

Figure 14: Supervision of the motor during converter operation

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