Smart energy savings
Energy savings through speed regulation

Danfoss, 2016

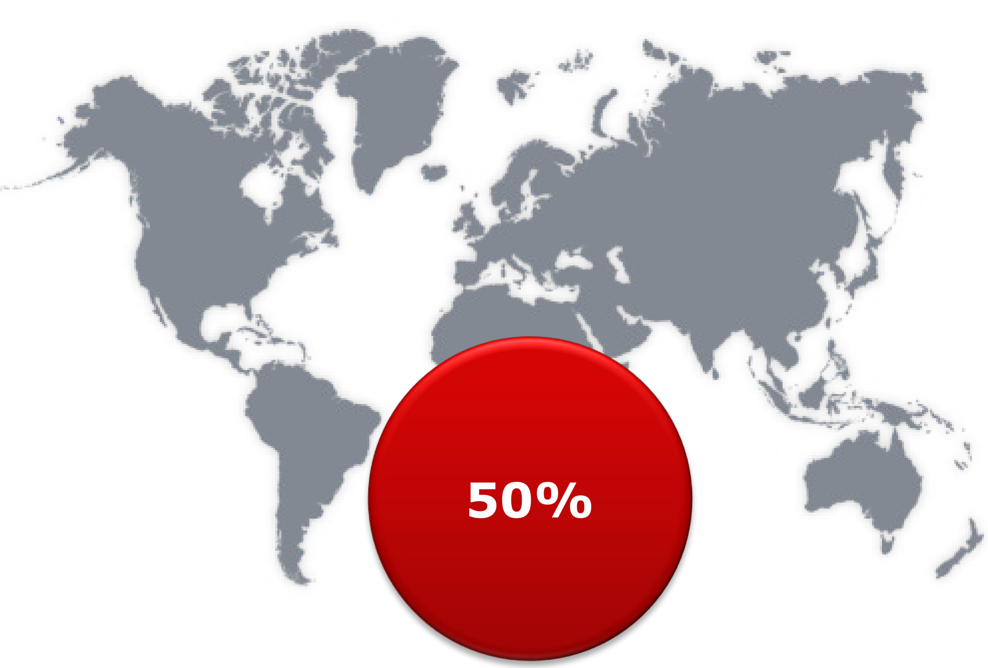
drives.danfoss.com

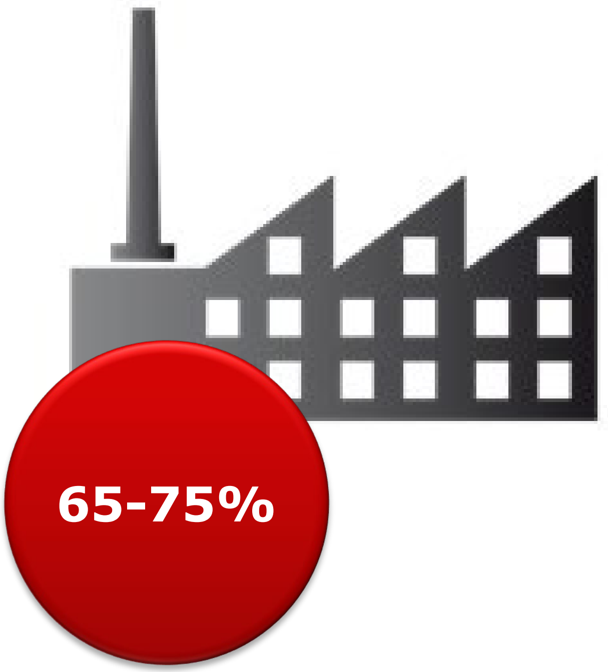
Agenda

- Energy consumption by electric drives
- Benefits of speed control
- Classification of drives
- Efficient motor technologies
- Recovery of energy into the line power
- AC drive functions for energy saving
- Smart savings
- Example – wastewater treatment plant (WWTP)

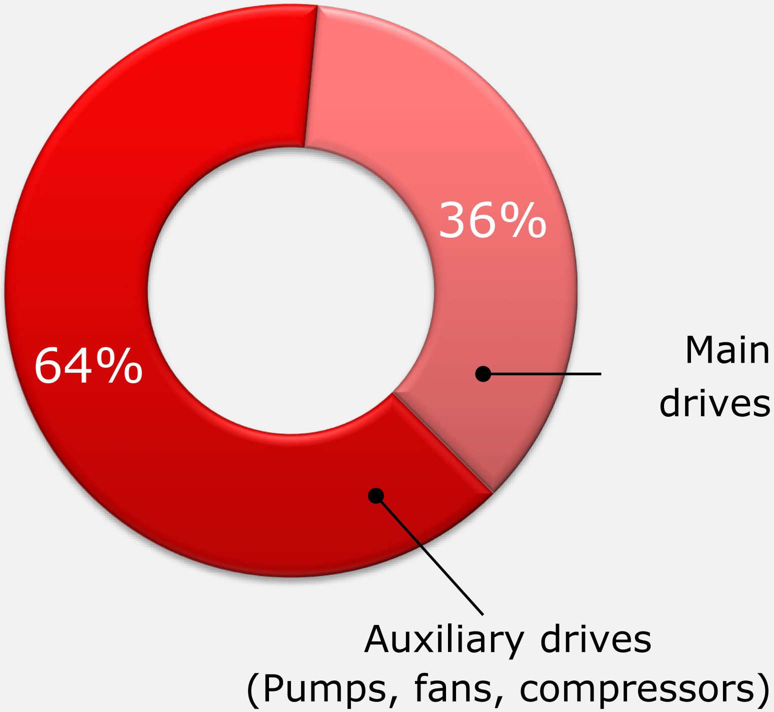
Energy consumption by electric drives

Proportion of energy consumption by drives





- Electric motors account for at least 50% of global electrical energy consumption
- In industry, the share is 65-75% depending on region and sector

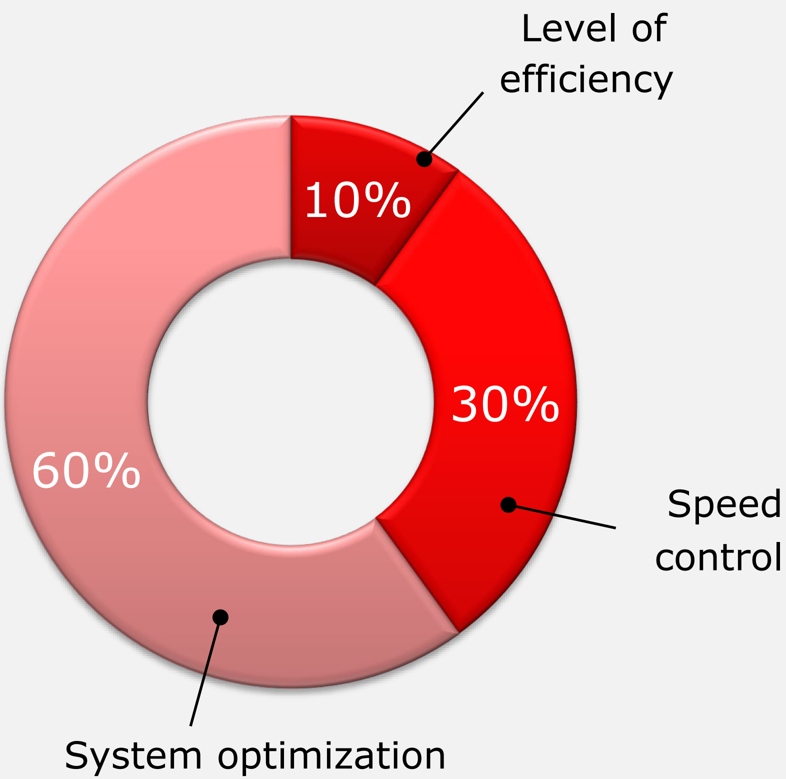


Who needs the energy?

- Main drives
  - Conveyor belts
  - Lifters
  - Extruders

- Auxiliary drives
  - Pumps
  - Fans
  - Compressors

Average values from various sources
(Fraunhofer Institut, Energieagentur Austria, EUP Lot 11 Motors Final Report)



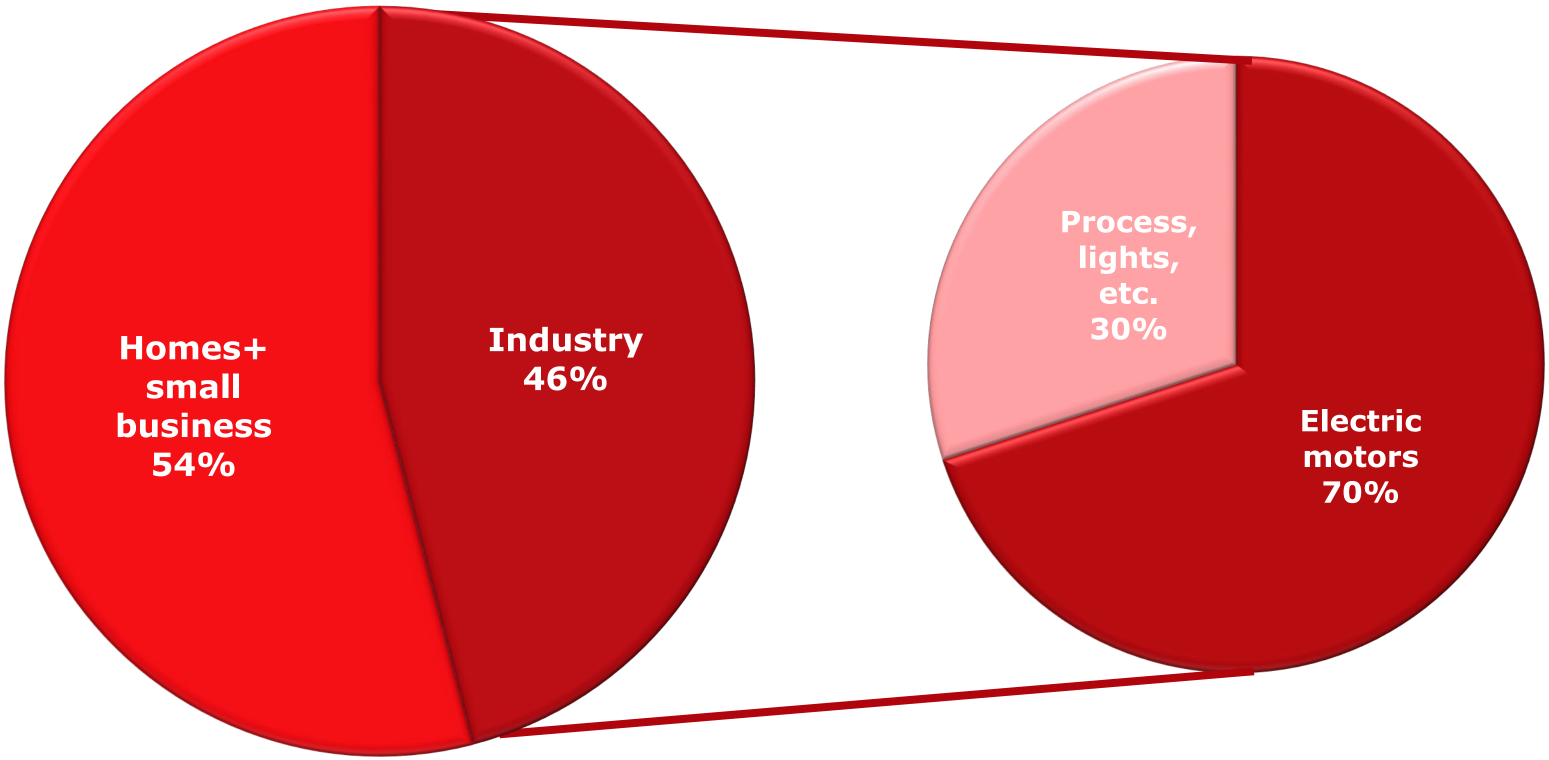
Source: Save Report of the EU & ZVEI (Electrical and Electronic Manufacturers' Association)

Potential savings

- 10%
  increase in the component efficiency level
- 30%
  conversion to speed control
- 60%
  optimization of the system or process

Classified as Business

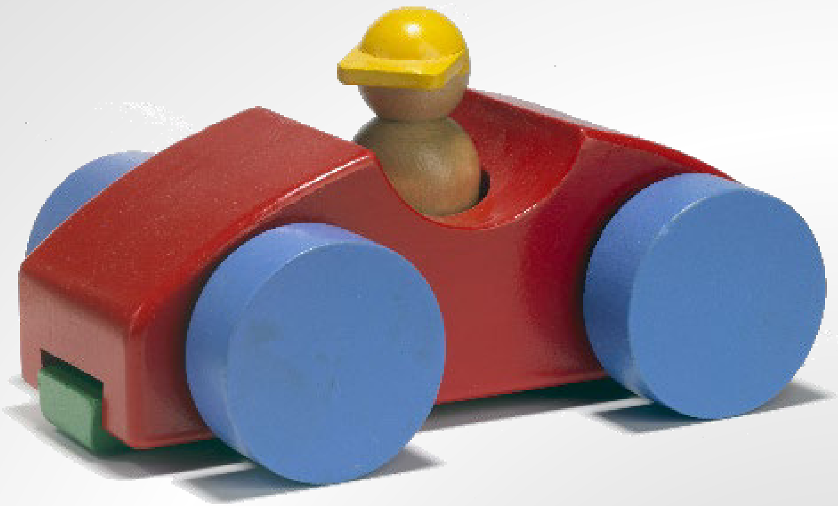
Electricity demand in Germany



- Electrical drives account for around 70% of energy consumption in industry
- This represents 175 TWh or around 30% of Germany's electricity consumption
- Energy-efficient motors can save 7 TWh
- The use of **speed control** saves 23 TWh

Source: ZVEI, 2014 - Energy efficiency with electrical drives

Benefits of speed control

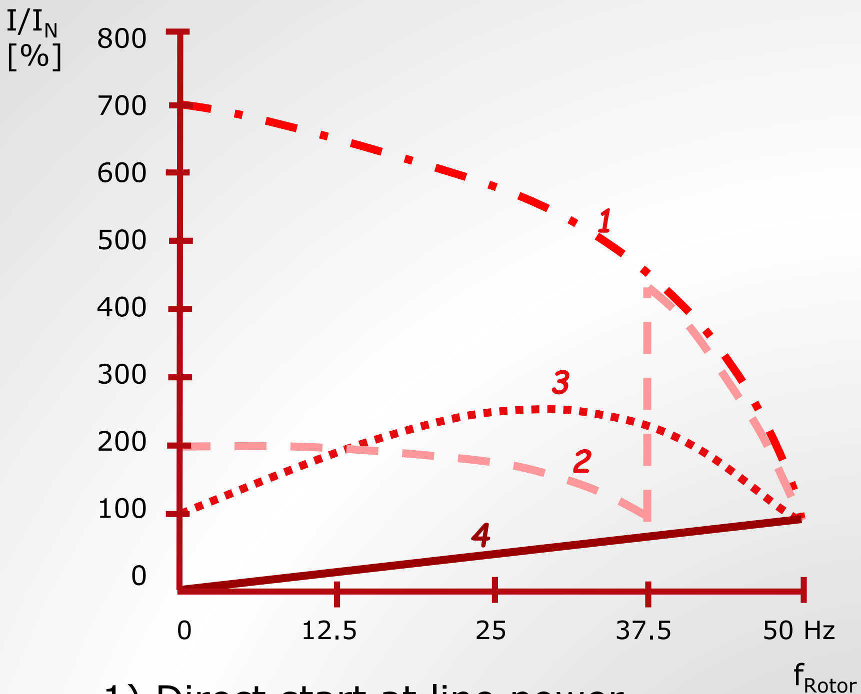


Speed control?

- Most widespread in industry:
  Three-phase induction motors
- Characteristics of three-phase induction motors:
  - Typically fixed speed
  - Special design for up to four speeds
  - Continuously variable control requires electronic controllers (AC drives)
- Benefits:
  - Process optimization
  - Reduction of mechanical wear and tear
  - Energy savings

Starting up electric motors

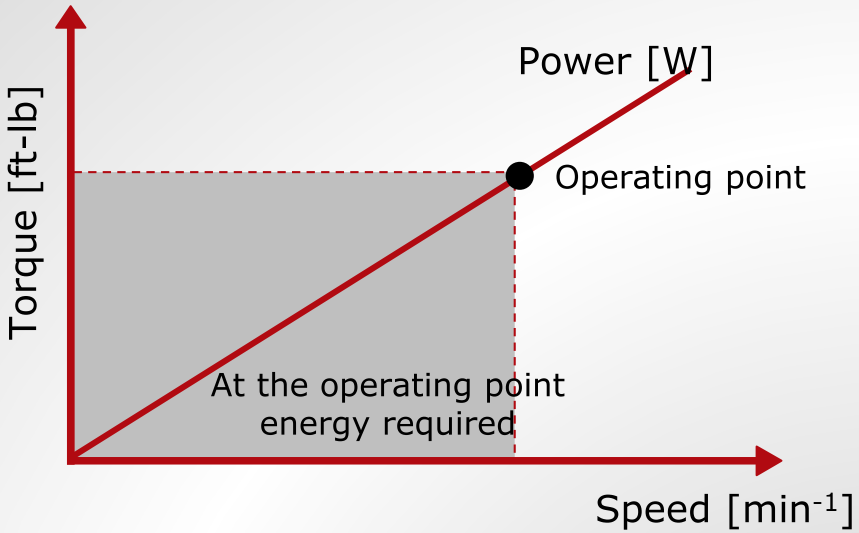
Start-up current, three-phase induction motor (quadratic load)



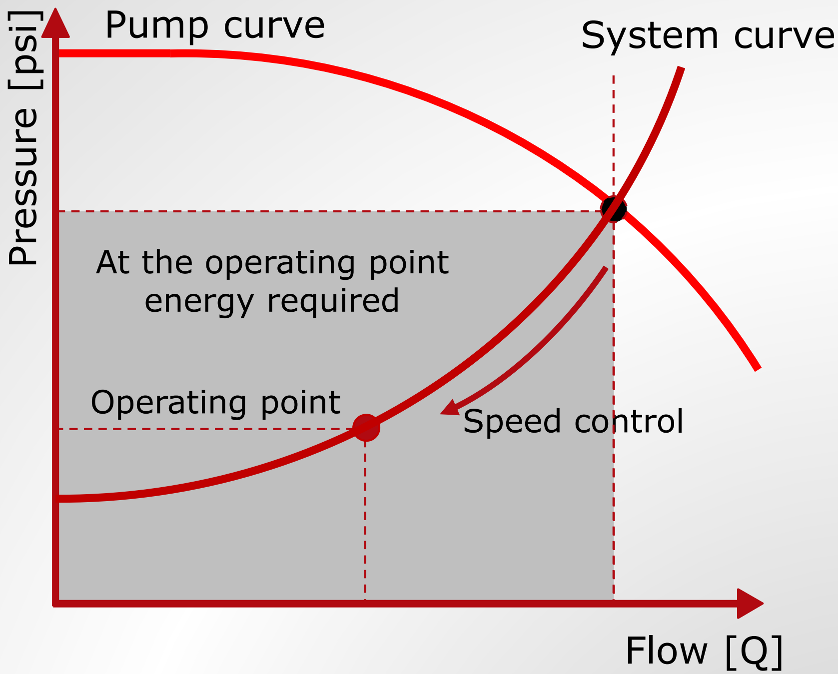
1) Direct start at line power
2) Star-Delta start-up
3) Soft starter
4) AC drives

- Three-phase induction motors require a high start-up current
- Power supply companies permit direct line power start-up up to approximately 4 / 7.5 kW
- Star-Delta start-up requires suitable motors
- Soft starter is available up to the MW range
- AC drive reduces start-up current and enables speed control

Savings with a constant load torque



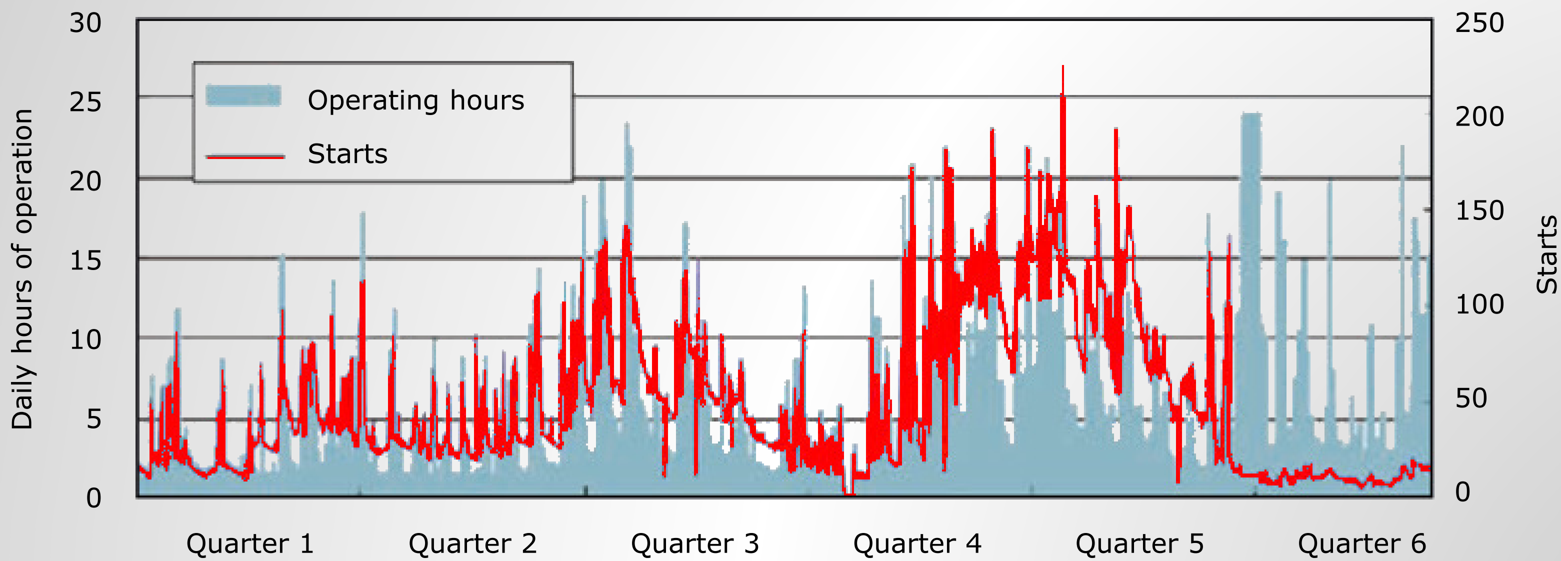
- Many main drives have a constant load torque requirement
  ($P_{mech} \sim M * n$)
- Load and slip compensation of modern controllers optimally adjusts power consumption to the load requirements
- Speed control enables:
  - Process optimization
  - Energy savings
  - Favorable transmission ratios
  - Reduced mechanical wear and tear



Savings with quadratic load torque

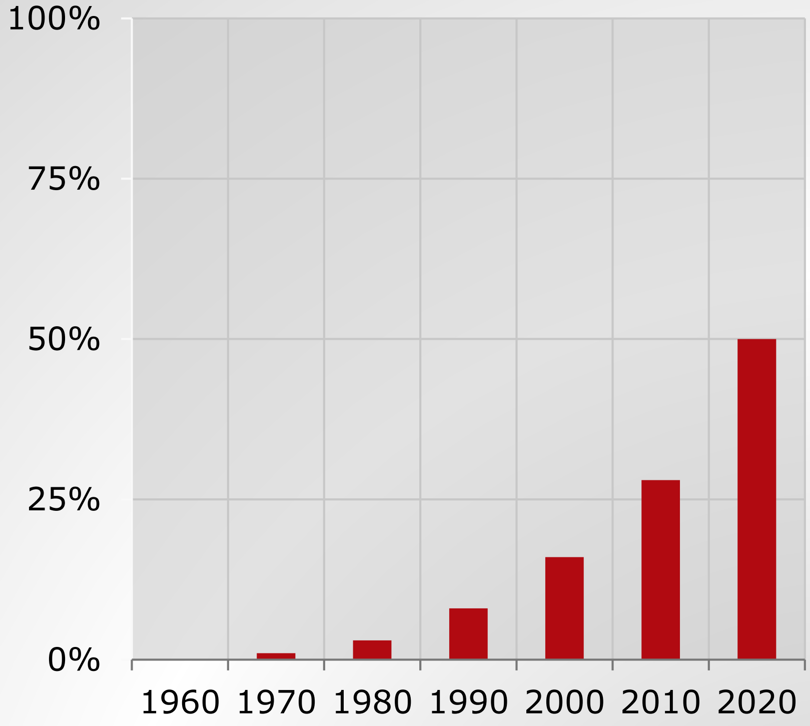
- Fans and many pumps have a quadratic load curve
- Power consumption is the cubic function of the speed
- Speed control almost always leads to considerable cost savings for applications with quadratic load
- Example: 20% less speed results in approx. 50% energy savings

Mechanical discharges



Practical example: Introduction of speed control in Q5 led to a reduction in starts from Q6

- The number of start-ups of a machine can be significantly reduced using speed regulation
- Fewer starts reduce mechanical and electrical loads resulting from surges during start-up
- Reduced speed reduces mechanical wear and tear in operation



ZVEI expects that by 2020, approximately 50% of new drives will be **speed-regulated**

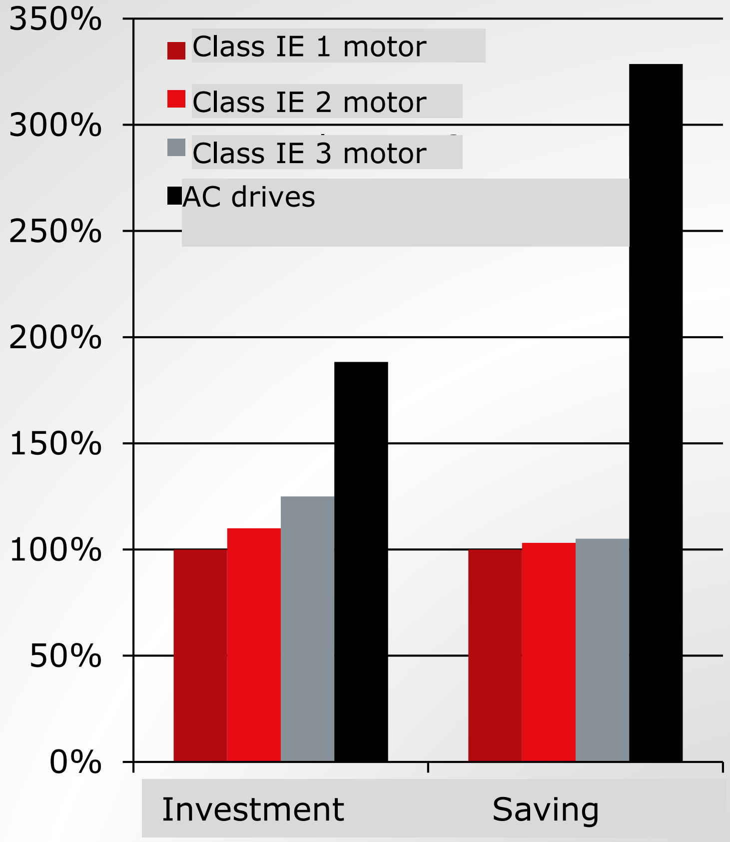
Speed control in the system

- Example water pumps:
  Annual potential savings from speed control: 35 TWh [1]
- "Risk"
  Use of AC drives without application of speed control results in increased losses (34 TWh [2])
- Speed control should only be used where it makes sense technically and energetically. This is the case in approx. **50-75%** of systems.

[1] Europump, 2013, Extended Product Approach for pumps

[2] CAPIEL, 2014, Ökodesign Anforderung für Elektromotoren – Hin zum System-Design

Cost/benefit comparison



Example: 7.5 kW motor systems

References: Cost: EuP Lot30 Task 2 – 5
Saving: ZVEI + Regulation (EU) 640/2009

Conclusion: Speed control

- Drive efficiency 96-98%
- High energy-saving potential in suitable applications
- Very good cost/benefit ratio
- Payback often less than 2 years
- Tried-and-tested technology in industry, business and households

Saves energy and reduces wear and tear!

Classification of energy-efficient components

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Efficiency

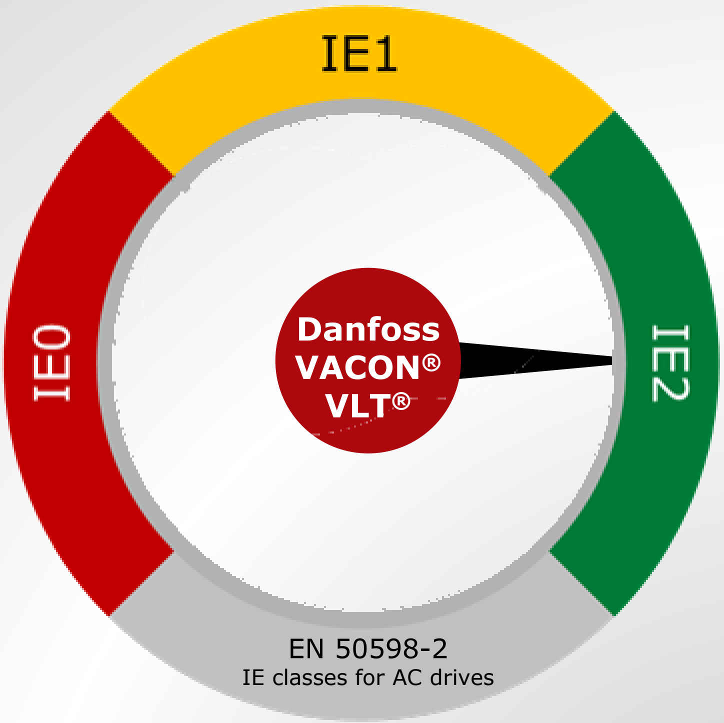
- The efficiency of a system consists of the multiplication of the individual efficiencies.

  $$\eta_{System} = \eta_{Part\ 1} \times \ldots \times \eta_{Part\ X}$$

- The typical components in a power drive system are:
  - Drive regulator
  - Motor
  - Transmission
  - Load-bearing machine

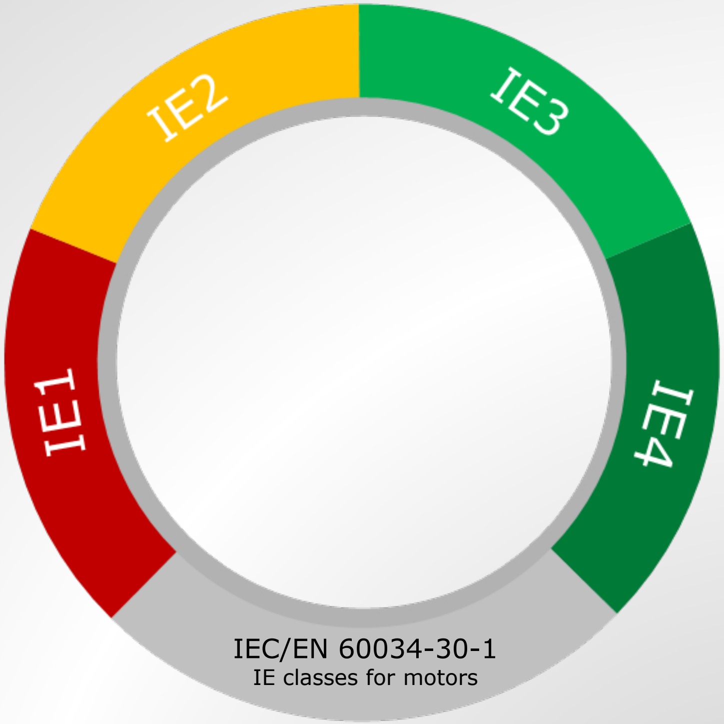
- For some components, IE classes (International Efficiency) and even statutory minimum values are defined

AC drives
EN 50598-2



- Describes the efficiency classes IE0-IE2 for AC drives, which meet the following conditions:
  - Single-axis AC/AC systems for 3-phase motors (three-phase induction, permanent magnet,...)
  - Input voltage: 100V – 1,000V
  - PDS rating: 0.12 – 1,000 kW
  - CDM rating: 0.278 – 1,209 kVA
- Except
  - Servo systems
  - AC drives with AFE
- Classification of a drive which is not in the scope of the standard (for example, AFE) is possible.

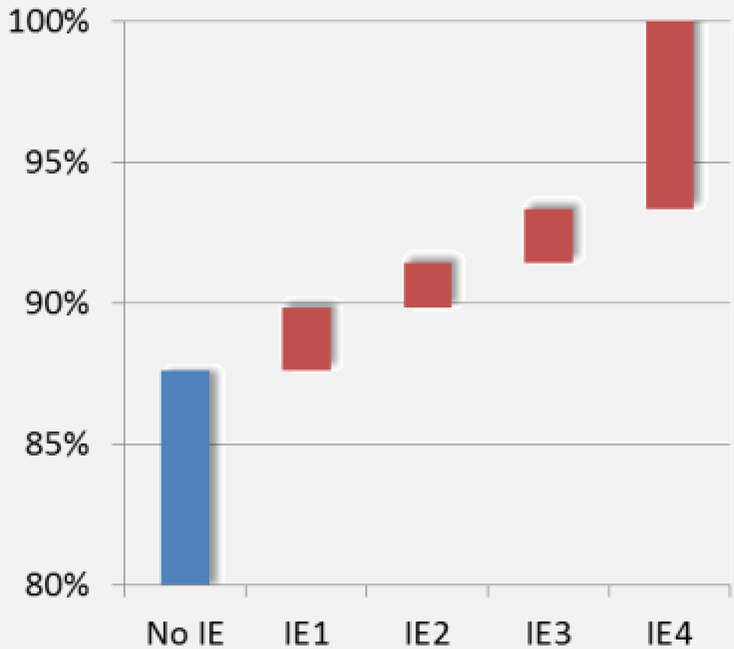
Motors on the line power IEC/EN 60034-30-1



- Defines efficiency classes IE1-IE4 for motors which start up and are operated on sinusoidal voltage.
- The classes are independent of the motor technology (for example, PM or three-phase induction motor)
- IE class is defined at the nominal working point
- Efficiency for 50% and 75% torque must be listed in the documentation
- Classes for motors connected to a drive are under discussion

IEC/EN 60034-30-1 Limits in detail

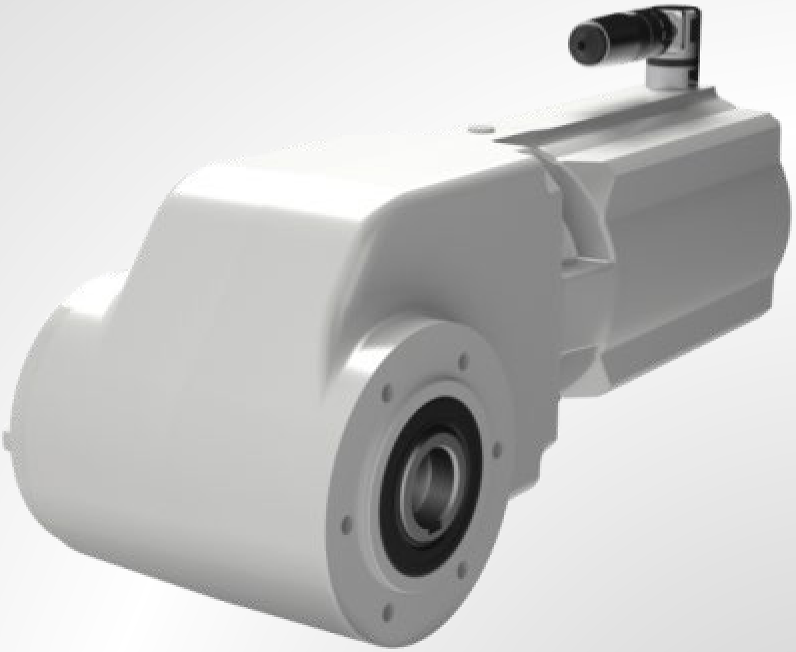
11 kW motor, 4 poles, 50 Hz



IE1 = 87.6% IE2 = 89.8%

IE3 = 91.4% IE4 = 93.3%

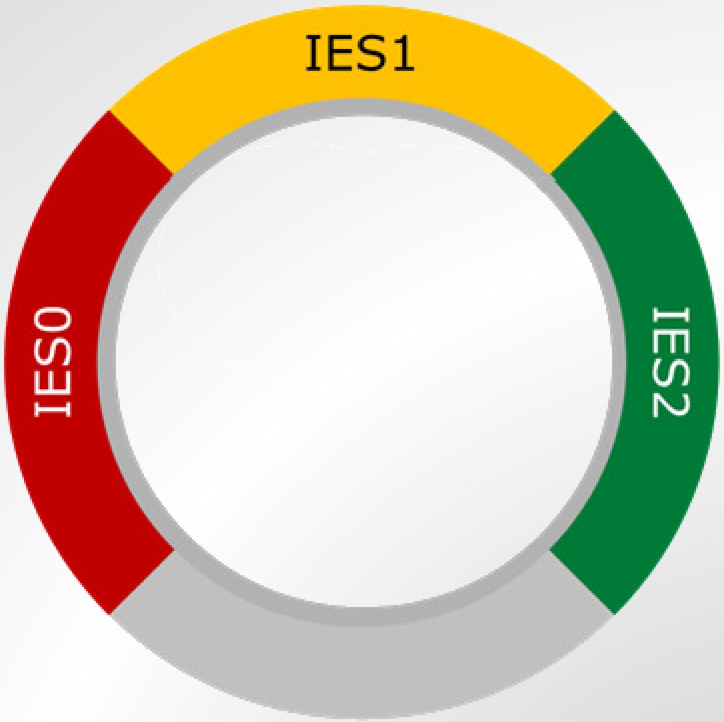
- IE classes are defined in bandwidths. Example 11 kW motor:
  - Class IE1: 2.3%
  - Class IE2: 1.6%
  - Class IE3: 1.9%
- Production tolerances influence actual efficiency
- In the case of checking through national market supervisors, the motor must adhere to the IE class, including tolerances
- The jump in efficiency between individual classes is small and reduces with increasing performance



Transmission

- Efficiency classes for transmissions are not defined
- Typical efficiency

Transmission	Efficiency
Direct driven	100 %
Spur gears	approx. 98%
Bevel gears	approx. 98%
Worm gears	50..90%
Flat belts	96…98 %
V-belts	92..94%
Serrated belts	96…98 %
Chains	96..98%



Drive + motor
EN 50598-2

- Describes the efficiency classes IES0-IES2 for drive and motor combinations.
- Validity is similar to the IE classes for AC drives
- Classification is made by:
  - Adding together the losses of the individual components (motor and drive)
  - Measuring the complete system

MEPS Timeline Europe

A new regulation (EU) 2019/1781 came into force on 1 October 2019.

European Regulation (EG) No. 640/2009 defines which **induction motors** must fulfill **M**inimum **E**fficiency **P**erformance **S**tandards (MEPS), and when.

Valid	Power	MEPS	MEPS alternative
01.01.2017	0.75 – 375 kW	IE3	IE2 + VSD

<table>
<tr><th rowspan="2">Valid</th><th colspan="2">Motor (2,4,6,8 pole)*</th><th colspan="2">VSD / Drive</th><th rowspan="2">MEPS alternative</th></tr>
<tr><th>Power</th><th>MEPS</th><th>Power</th><th>MEPS</th></tr>
<tr><td rowspan="2">01.07.2021</td><td>3~ 0.12 – 0.75 kW</td><td>IE2</td><td rowspan="2">3~ 0,12 – 1000 kW</td><td rowspan="2">IE2</td><td rowspan="2">omitted</td></tr>
<tr><td>3~ 0.75 – 1000 kW</td><td>IE3</td></tr>
<tr><td rowspan="5">01.07.2023</td><td>1~ ≥0.12 kW</td><td>IE2</td><td rowspan="5"></td><td rowspan="5"></td><td rowspan="5">omitted</td></tr>
<tr><td colspan="2">2,4,6 pole</td></tr>
<tr><td>3~ 75 – 200 kW</td><td>IE4</td></tr>
<tr><td colspan="2">Ex eb - 2,4,6,8 pole</td></tr>
<tr><td>3~ 0.12 - 1000 kW</td><td>IE2</td></tr>
</table>

*Starting on 01.07.2022, motor part load losses for operation at VSD must be provided

Efficient motor technologies driven by AC drives

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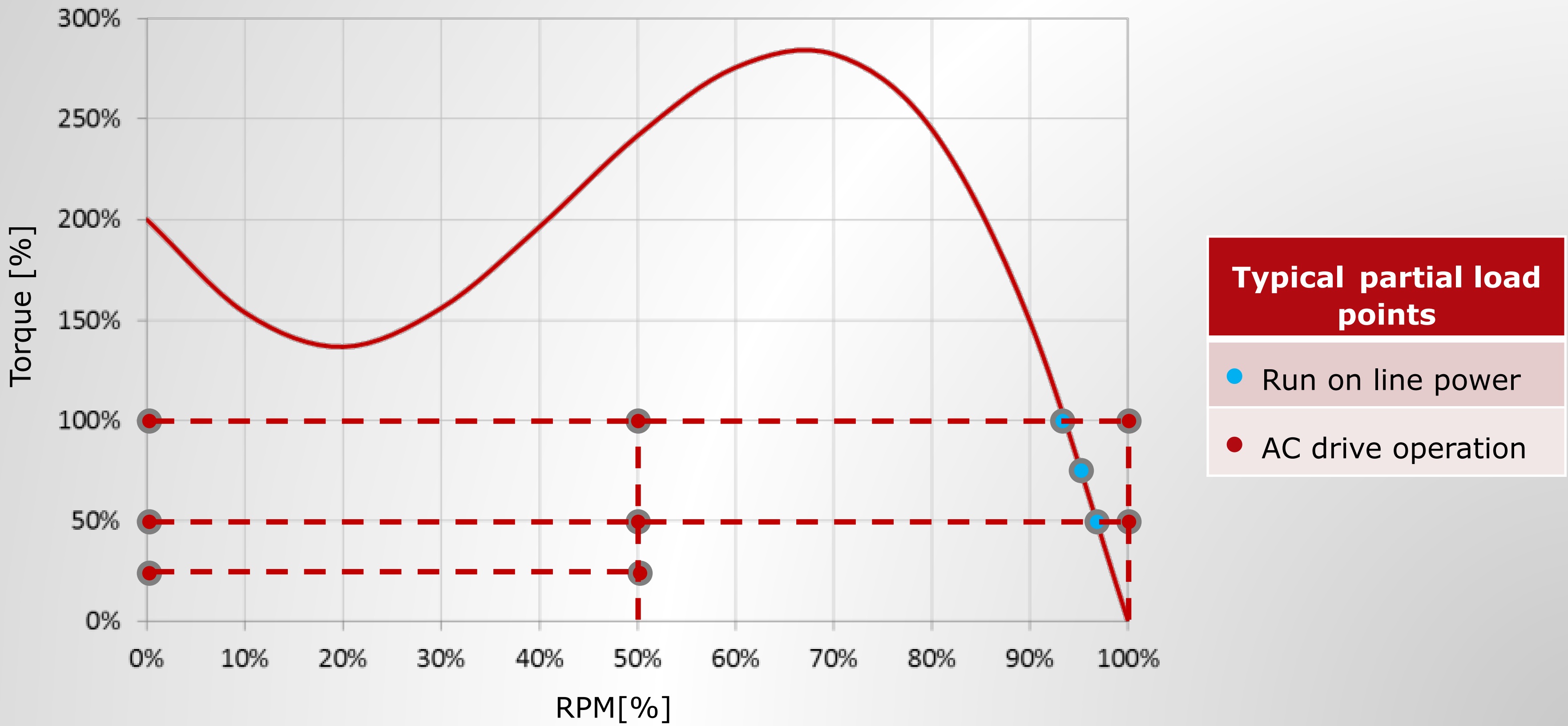
Current motor technologies

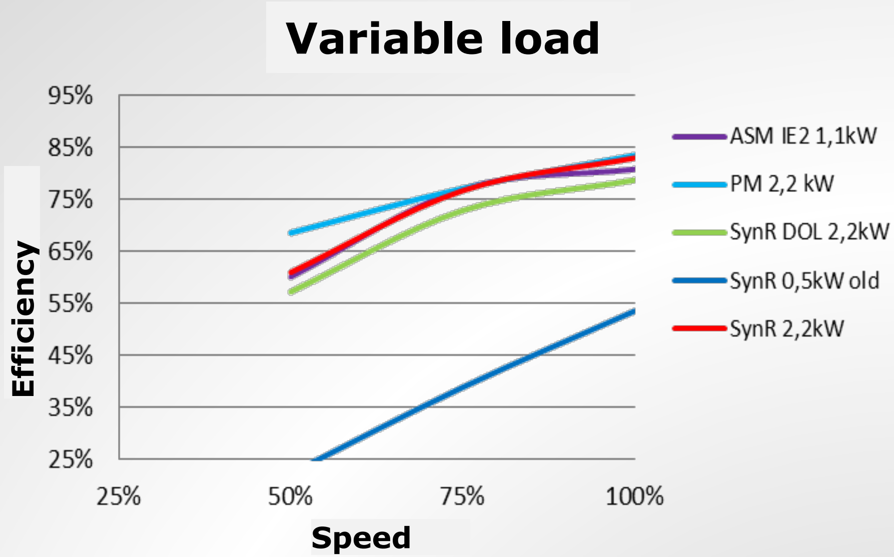
- Focus on energy efficiency leads to further development of a number of motor technologies
- Motors are generally optimized for line power or AC drive operation
- IE class is not a characteristic of a particular technology!
- Technologies differ in the way that they behave under partial loads. A motor using one particular technology is not intrinsically more efficient than another. It depends on the application.

What is partial load?



- Traditional: Efficiency of line power operation with different load torque
- Speed control: Different torque at different speeds

Partial load on the AC drive



- The energy benefit of the AC drive is in the speed control

- Partial load efficiencies depend on
  - Motor technology
  - Power
  - Design
  - Control

IMPORTANT: Not every controller supports all modern motor types

Motor commissioning

- Default setting of many AC drives already enables the operation of three-phase induction motors
- Motor-specific basic data are required for optimum operation
  - Motor types (three-phase induction, PM, SynRM)
  - Performance
  - Current
  - Speed
  - Frequency
- Automatic adaptation functions can measure extended data

Pre-assembled or optimized?

- Pre-assembled drive packages firmly link the drive to the motor.
  - "Safe" selection
  - Inflexible
  - Potentially limited availability in the case of delivery bottlenecks or export

- Adapted assignment (motor or AC drive manufacturer or project designer)
  - One-time expense
  - Optimized for application
  - Easy to replace – worldwide
  - No efficiency disadvantage in the case of suitable control algorithms, as is normal at Danfoss.

Comparative overview

Motor	Max. efficiency class	IEC enclosure	AC drive operation	Comments
Three-phase induction motor	IE3/IE4	Potentially not compatible with IE3	No problems	IE3/IE4 or IEC mounting dimensions, where applicable, are not complied with.
Three-phase induction motor CU rotor	IE3/IE4	Compatible. Can also be smaller.	No problems	Higher start-up power and different start-up torque in comparison to three-phase induction motor.
PM	IE3/IE4	Compatible. Can also be smaller.	Always needs a controller (possibly with encoder) Often improved efficiency at low speeds.	Occasional high costs for required rare earth elements. Current price trend downward.
LSPM	IE3/IE4	Compatible. Can also be smaller.	Efficiency can be approximately 5 to 10% lower than line power operation	Motor with very good level of efficiency. Constraints in the application should be noted.
SynRM	IE2–IE4	Compatible. Can also be smaller.	Always needs a controller (note higher apparent performance!!). Potentially improved efficiency at low speeds compared to PM.	Only new designs are optimized for energy efficiency. Line-start variants have some constraints in drive operation. SynRM with ferrites is in development.

Recovery of energy into the line power

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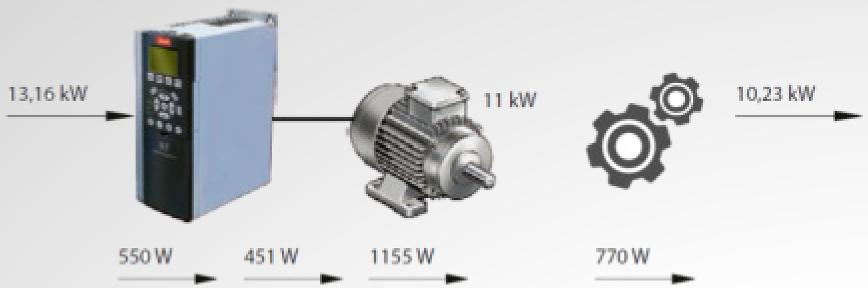
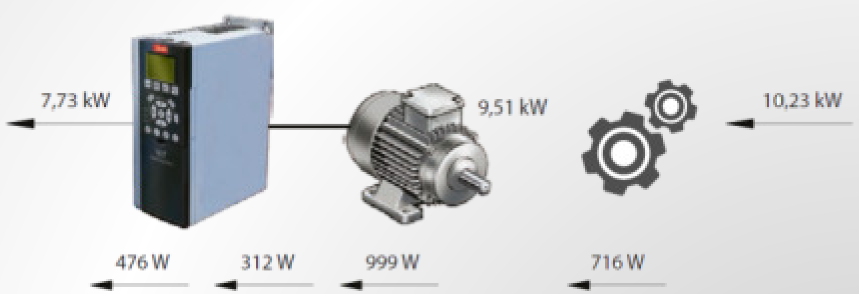
Use regenerative energy

- An induction motor works as a generator when it runs faster than its synchronous speed.
- Most applications generate energy during the deceleration processes
- The energy generated can be used through:
  - DC link
  - Recovery of energy into the line power

Available energy



System losses during motor operation



System losses during regenerative operation

- Energy difference between start and end of a deceleration:
  - Maximum: 50%
  - Typically: 10-20%
- Losses in the system reduce the amount of energy that can be recovered:
  - Motor
  - Cable
  - AC drive
- Due to oversizing, the maximum energy only corresponds to the motor rated output in rare cases.

Recovery drives

- Recovery drives require an active input rectifier
- Active rectifiers can have losses that are twice as high as a normal rectifier
- Higher losses by the active rectifier are effective in:
  - Motor mode
  - Partially in standby mode

When does recovery make sense?

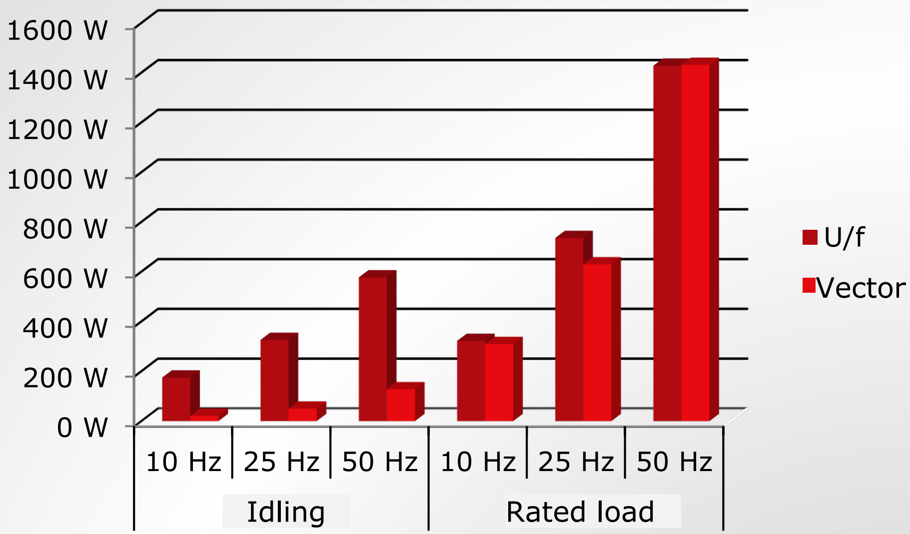
- Decisive for efficiency
  - Quantity of recovered energy
  - Load cycle - How often is the energy available?

- Typical applications in which recovery of energy makes sense:
  - Elevators
  - Cranes
  - Centrifuges
  - Hoists

- In some instances, brake resistors can be replaced

Energy-saving functions in the AC drive

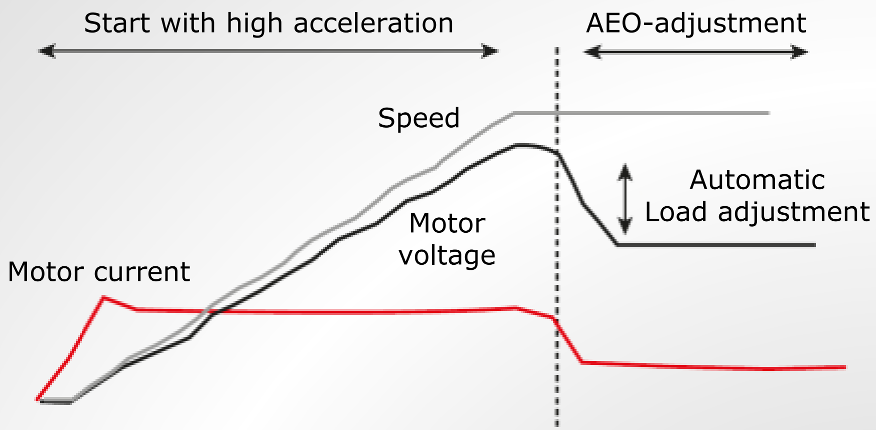
Adapted control



Example: Power consumption of motor with different control strategies

- All motors operate by applying the correct voltage at a given frequency (U/f characteristic)
- A rotating shaft does not mean, however, that the motor is operating efficiently.
- Not all AC drives provide the full AC line voltage at the output.

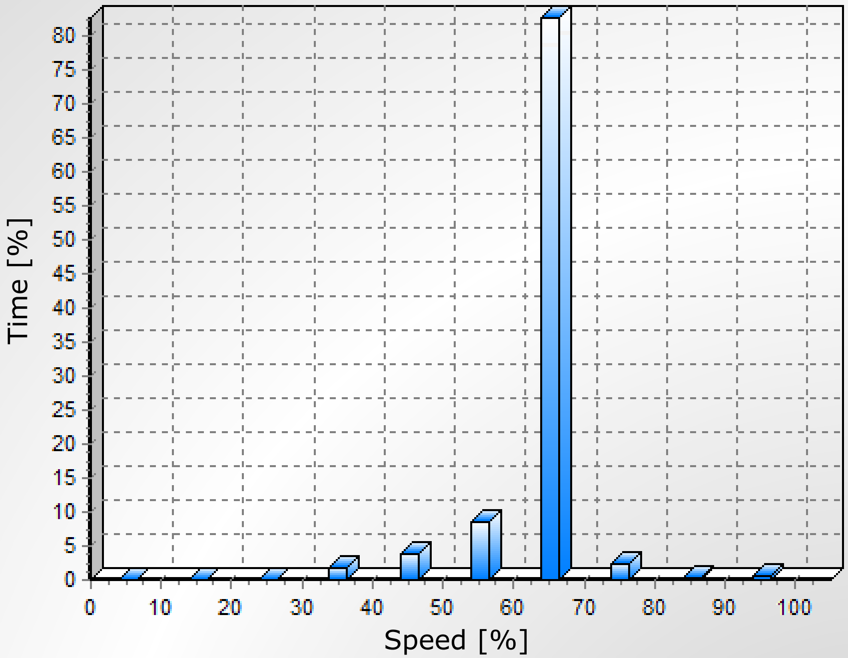
  Reduced voltage leads to a higher motor current and additional losses.
- Optimal operation is only possible with adapted control strategies



Automatic Energy Optimization

- In stationary operating states, the energy consumption can be reduced by adapting the magnetization level.
- An optimized balance between energy saving and having enough magnetization for sudden load peaks must be found to ensure reliable operation.
- Average potential savings for AC drives with a small to medium enclosure size: 3-5 %

Integrated energy loggers

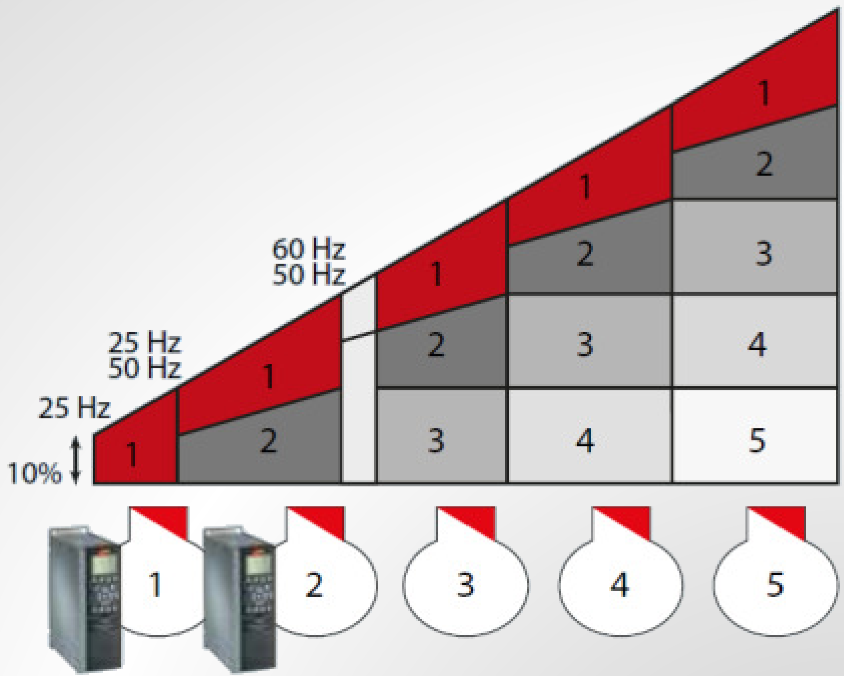


Example: Load trend read out from
Danfoss VLT® HVAC Drive with VLT® Energy Box

- AC drives enable a quick analysis of the application's energy consumption
  - Current electricity/voltage demand
  - kWh counter
  - Trend functions
  - Energy log

- Real load profiles can be determined in operation. These profiles can be used in energy optimization software such as VLT® Energy Box

Cascade control



Example: Cascade control for compressors.
Two compressors are speed-controlled. Additional compressors are connected where necessary.

- In many applications, it is sensible to use several smaller motors instead of one large motor
  - Motors are operated with better efficiency
  - Additional motors are connected where necessary

- Typical applications
  - Pumps
  - Compressors
  - Fan (fan wall)

Application-specific functions

- Sleep Mode
  If no water withdrawal occurs in a pump system, the motor is stopped

- Belt breakage
  Detects belt breakage, for example in ventilation systems, and therefore whether there is any point in running the motor.

- Dry run protection
  Motor is only operated if a medium is actually supplied.

- And much more

Smart savings

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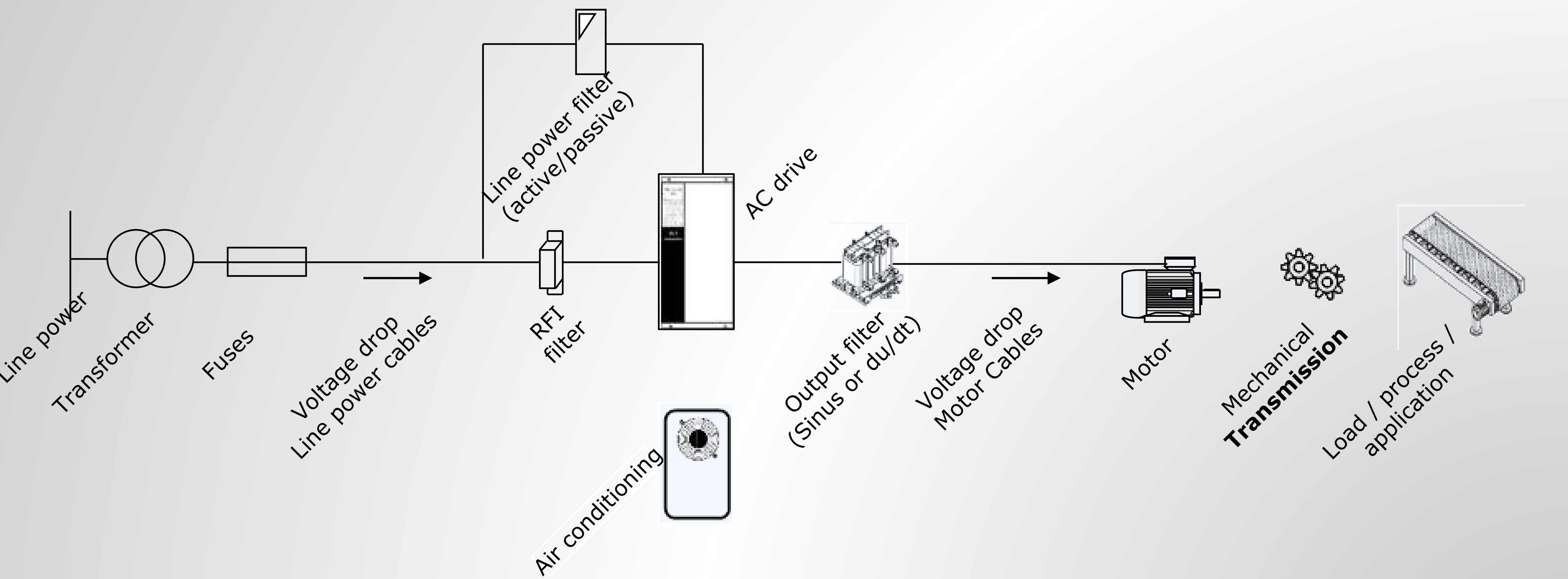
Look at the entire drive train!



- Only with an overall view can you assess the advantages and disadvantages
- Additionally: consider and optimize the service life of the respective drive

First step: IE class

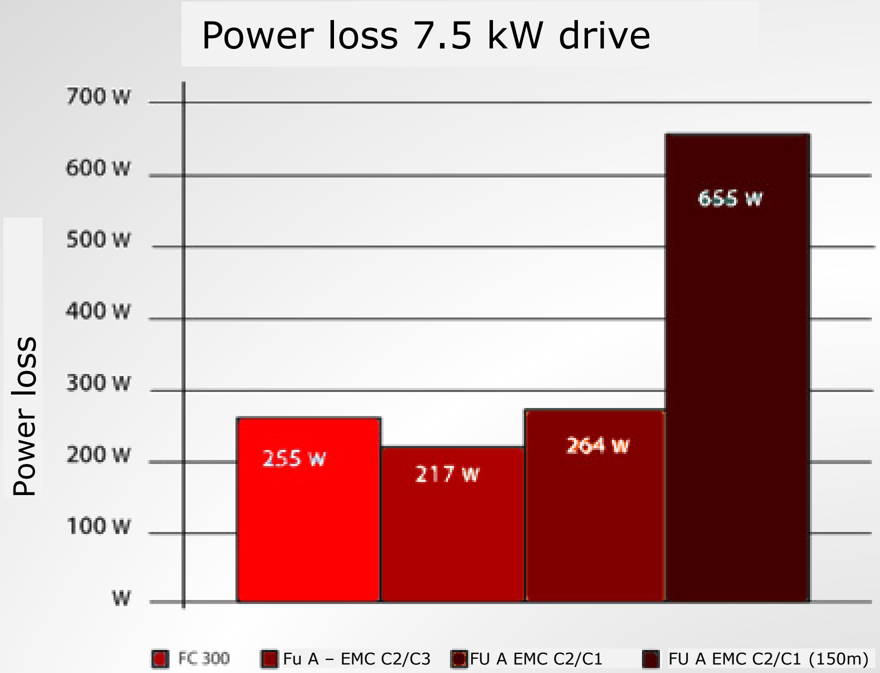
- IE/IES classes help in making a first assessment
  - Efficiency of the components / of the power drive system
  - Classes only apply **at the nominal operating point**
  - Additional options are often **NOT** considered
- Also think about
  - Behavior under partial load
  - Line power/EMC filter
- With specific power drive systems, the user must check what is contained in the package of options.

EMC - It's the total interference that counts

- EMC problems include a wide range of phenomena
  - Line power Interference
  - Conducted interference
  - Line power related faults

- Interference grows with an increase in the number of installed devices, until "the final straw" - in other words, the system no longer tolerates the accumulated total measurement of the EMC faults.
- EMC filters **do not have to be included as standard** in units.
- Separate and add-on suppression is possible, but causes additional losses and costs

Internal or external filters?

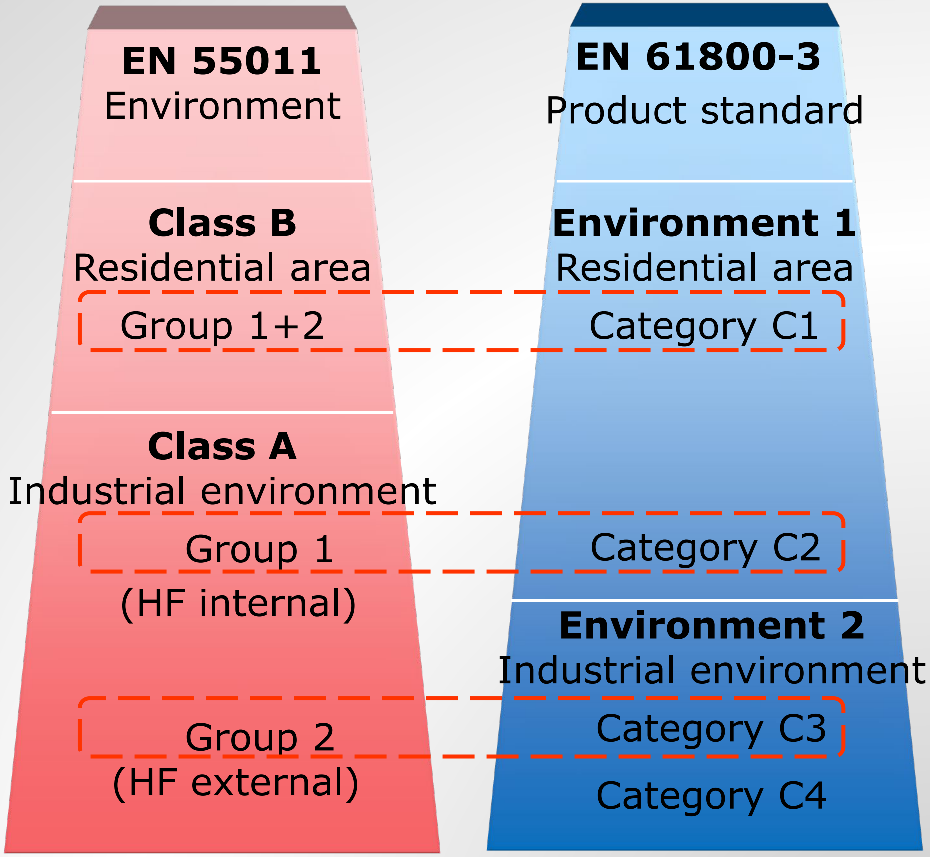


Example

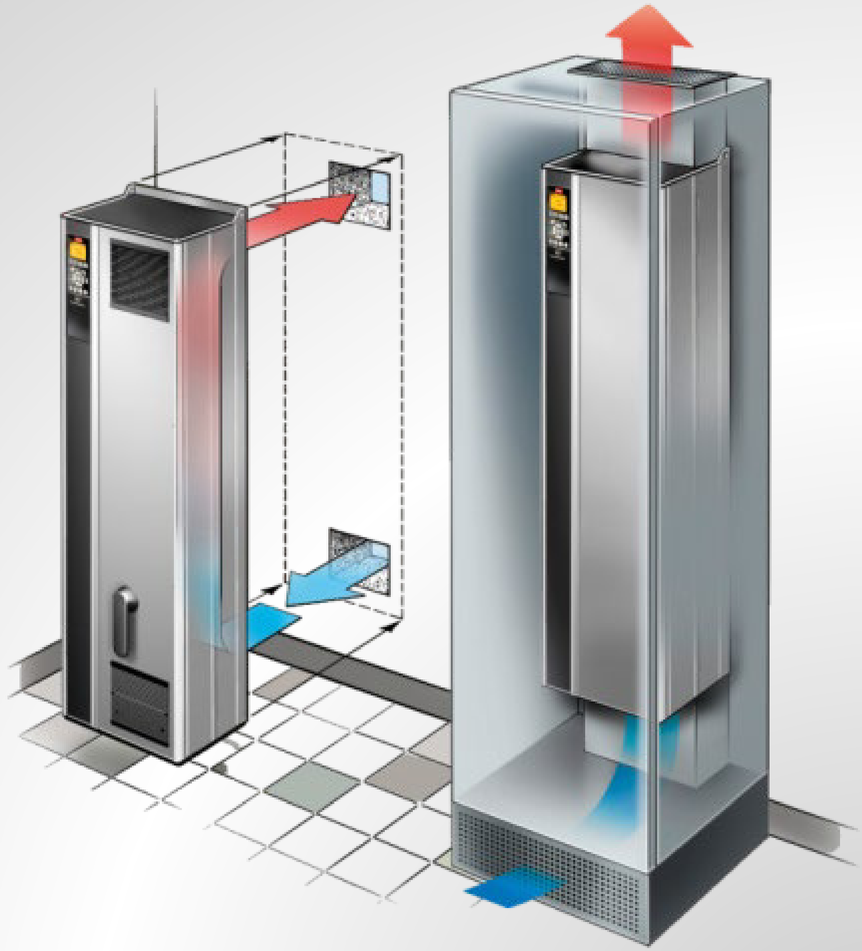
Additional losses	400 W
Service life	60 000 hours
Energy price	EUR 0.08/kWh
Additional costs	**EUR 1920**

- External filters always generate additional losses
- In the case of integrated filters, filter losses are included in the specified power loss.
- Space and air conditioning requirements for external filters must be considered in the control cabinet
- It is therefore better to pay attention to selection of the right filter during project planning

Which EMC filter is the right one?



- Inadequate filter measures are often only identified later on.
- Subsequent measures result in higher costs compared to those planned in advance.
- Recommendation
  - Residential/commercial environment
    EN 55011 - Class B
    (Limits EN 61800-3 C1)
  - Industrial environment
    EN 55011 - Class A1
    (Minimum EN 61800-3 C2, or C3 for larger power sizes and C4 for insulated systems)



Control cabinet air conditioning

- Additional losses in the control cabinet increase the air conditioning requirements
- Avoid installation of external filters
- Extract heat from control cabinet
- Use rear wall cooling
- Position brake resistors outside of the control cabinet
- Use software functions (for example, AC brake)

Your knowledge matters!

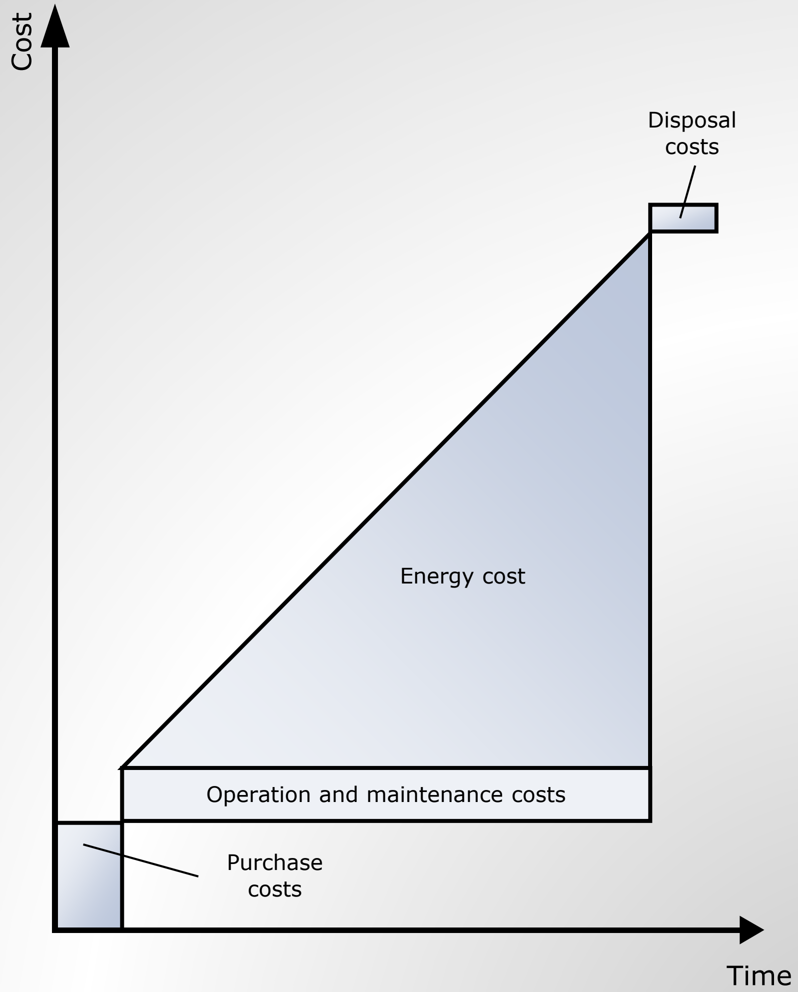
- Only people with precise system and specialist knowledge can:
  - Evaluate positive and negative effects on the system
  - Reduce unnecessary design safety margins
  - Estimate the expense for implementation of individual measures

- Measures can only be used in a targeted manner if the behavior of the entire system is taken into consideration

Important: Analyze energy requirements

- Identifies the big consumers and specifies approaches for planning initial measures
- Enables the checking of measures taken and their effectiveness
- Data collection can be done by means of external recorders, functions in the AC drive, trend acquisition of SPS, and many other ways

Caution when measuring and evaluating electrical values which were measured upstream or downstream of AC drives

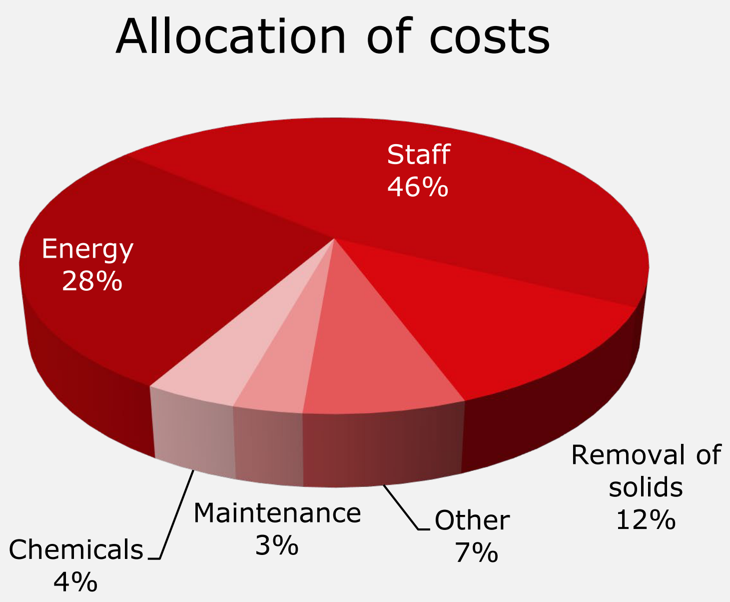


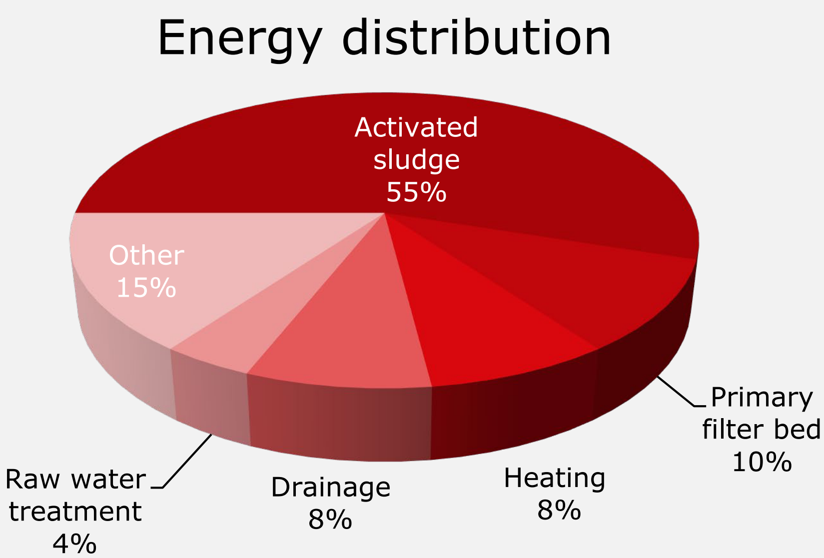
Smart savings

- Save energy, but not at any price
- Every measure has side effects. Weigh the side effects up against the advantages
- Low purchase costs seldom mean automatically low operating costs
- Consult experts where necessary to clarify technical advantages and disadvantages

Application options in practice
Example: Sewage treatment works

Costs of wastewater treatment

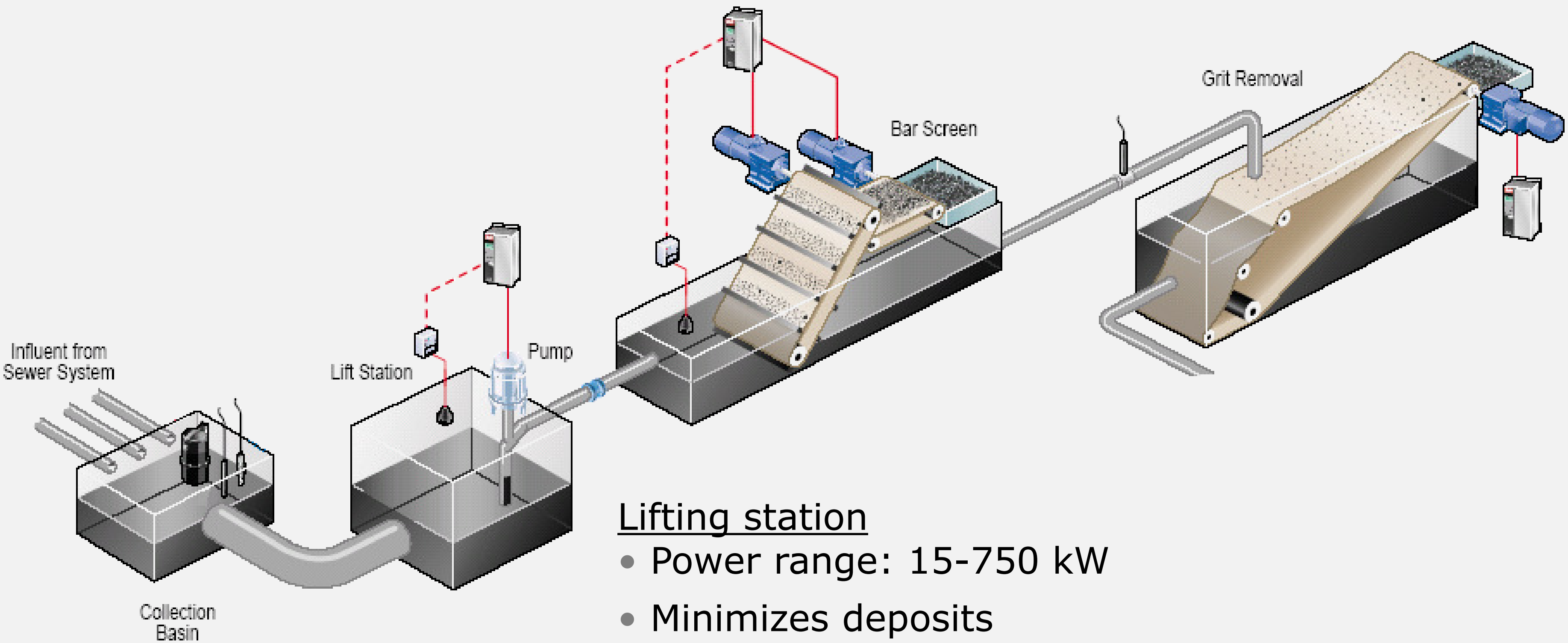




- Energy requirements account for some 25-40% of the overall costs
- Modern drive technology enables the reduction of costs in all areas
  - Lifting station
  - Pre-machining
  - Primary treatment
  - Secondary treatment
  - Sludge treatment
  - Sludge disposal
  - Tertiary treatment

AC drives in pre-treatment

Removal of solids which could endanger the pumps



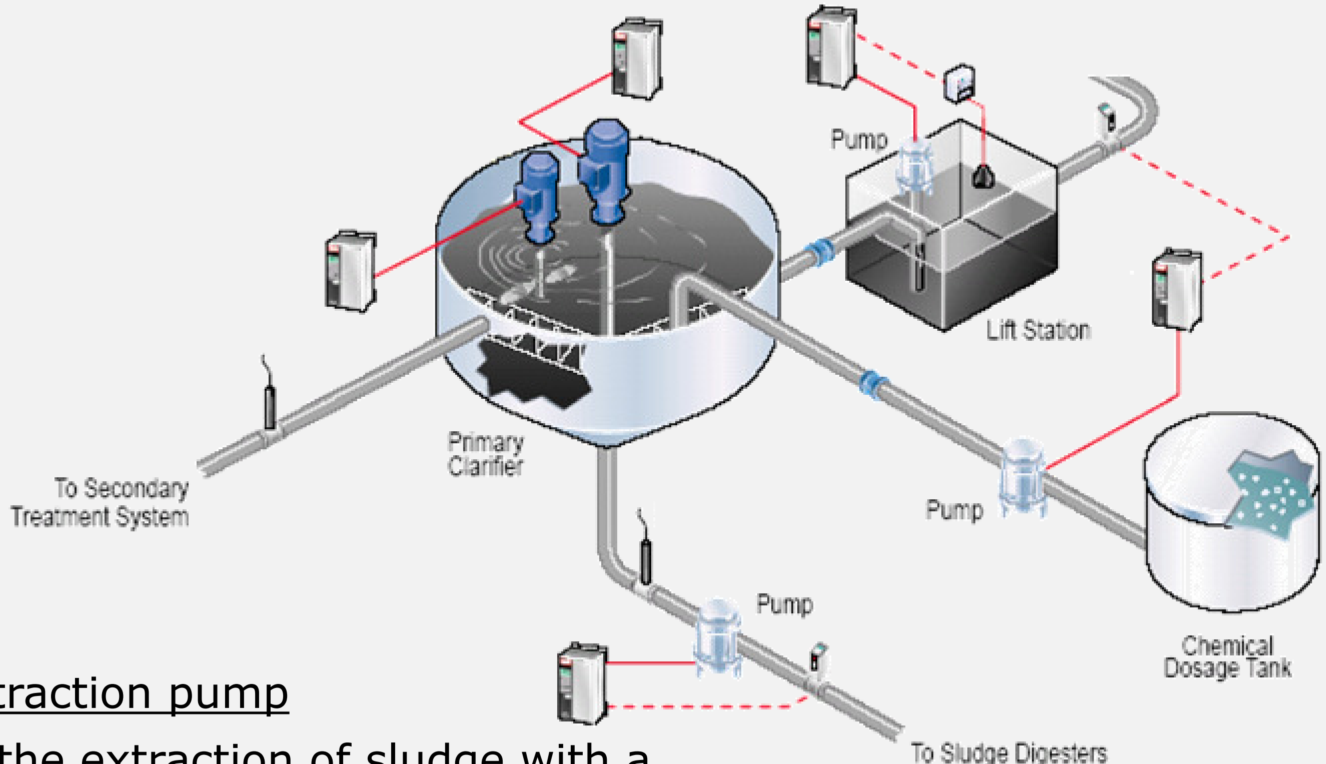
<u>Lifting station</u>

- Power range: 15-750 kW
- Minimizes deposits
- Decreases irregular flow
- Eliminates water surges
- Reduces starting and stopping
- Deragging

By way of example, only one application of the process is described

Primary treatment

Removal of organic/inorganic sediments and solids



<u>Sludge extraction pump</u>

- Enables the extraction of sludge with a minimal residual water content
- Soft starting + stopping
- Reduces energy and maintenance costs

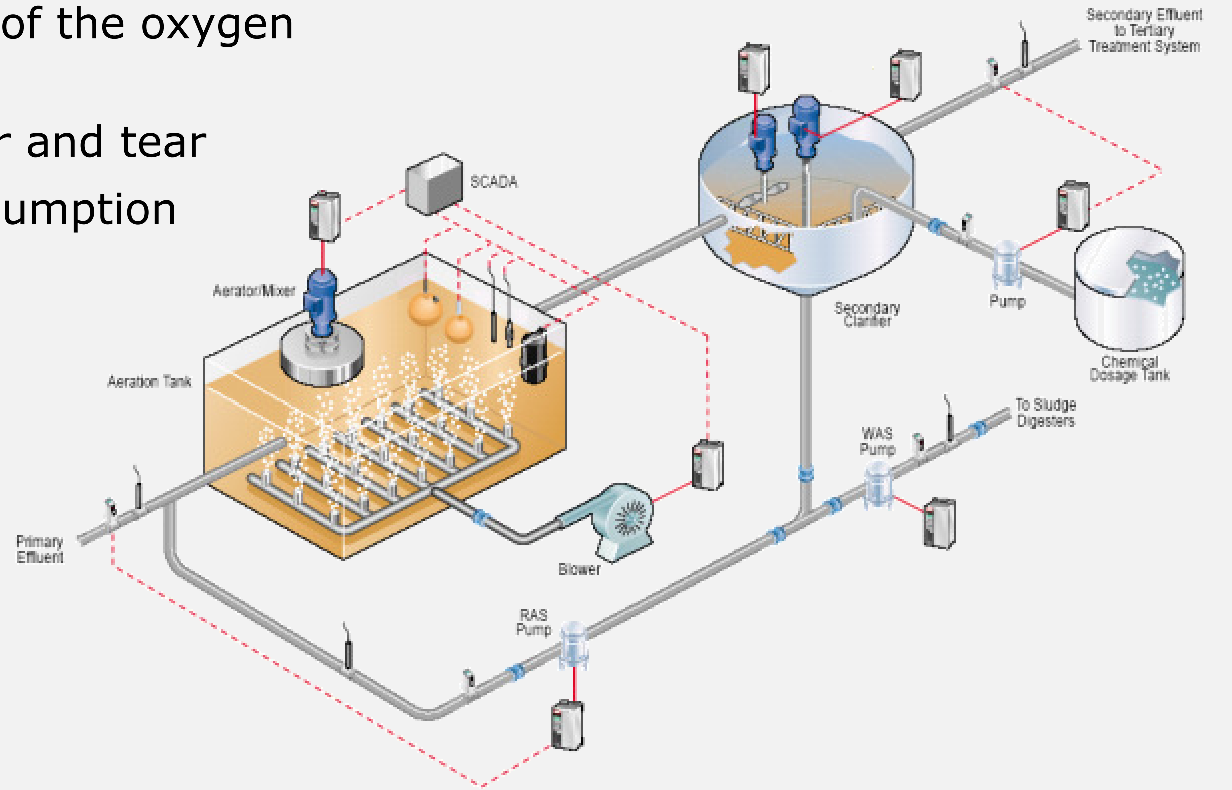
By way of example, only one application of the process is described

Secondary treatment

Biodegradation of suspended solids + dissolved organic solids

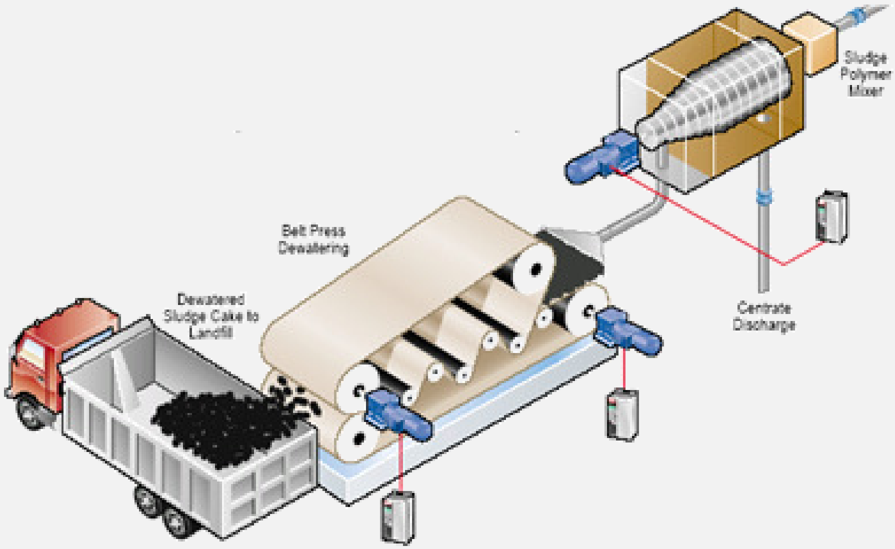
<u>Aeration tank</u>

- Process improvement through more precise control of the oxygen content
- Reduce stress + wear and tear
- Reduced energy consumption



By way of example, only one application of the process is described

Dewatering and sludge processing



<u>Dewatering</u>

- Power range:15-400 kW
- Optimal sludge supply
- Optimal speed of the centrifuge
- Higher dewatering efficiency
- Drier filtrate

By way of example, only one application of the process is described

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