



ABB drives

# Technical guide No. 4

## Guide to variable speed drives

Power and productivity  
for a better world™





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# Chapter 1 - Introduction

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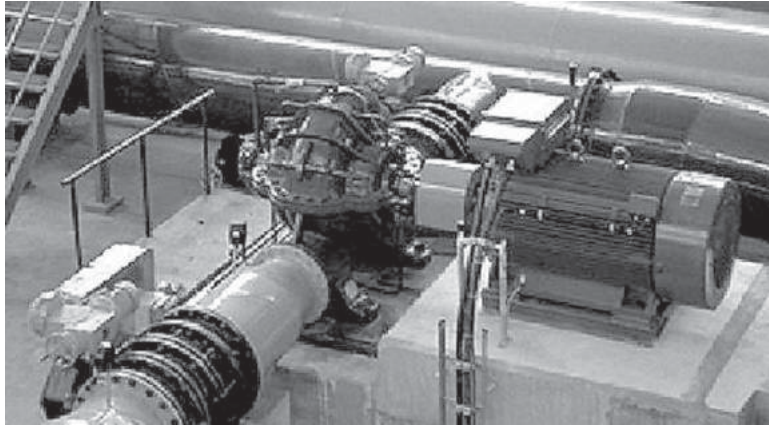
## General

This guide continues ABB's technical guide series, describing different variable speed drives (VSD) and how they are used in industrial processes. Special attention has been given to electrical VSDs and especially to AC Drives.

The guide tries to be as practical as possible. No special knowledge of VSDs is required, although basic technical know-how is required to fully understand the terms and descriptions used.

## Chapter 2 - Processes and their requirements

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### Why variable speed control?

To understand why variable speed control is necessary, we first need to understand the requirements of different processes. These processes can be divided into two main categories; material treatment and material transport, although there are many different sub-categories that come under these two basic headings.

Common to both main categories, however, is the need to be able to adjust the process. This is accomplished with VSDs. This chapter describes the main industrial and non-industrial processes using VSDs.



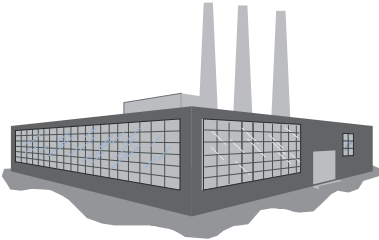
Examples

Industrial:

- Chemical industry
- Pulp, paper, printing
- Food & beverage
- Power plants
- Mining
- Metal industry
- Machine shops
- Plastics
- Textiles

Non-industrial:

- HVAC
- Water treatment

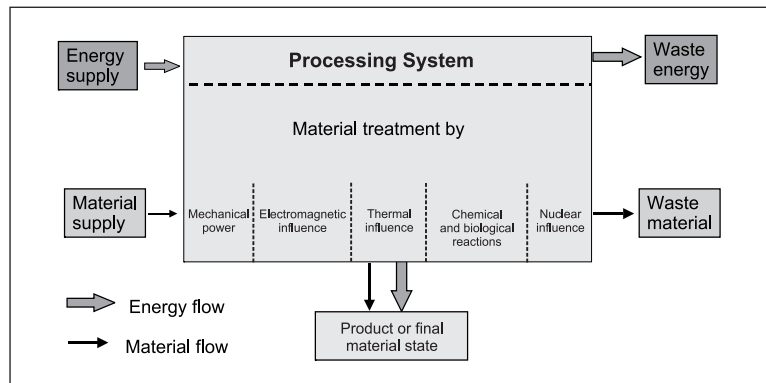


Industrial segments with VSD processes

Industrial processes are numerous, and the list above mentions just some of the industrial segments with VSD processes. What they have in common is that they all require some kind of control using VSD.

For example, in air conditioning applications (part of HVAC), air flow requirements change according to the humidity and temperature in the room. These can be met by adjusting the supply and return air fans. These adjustments are carried out with VSDs.

Fans are also used in power plants and the chemical industry. In both cases, the fans need to be adjusted according to the main process. In power plants, the main process changes due to varying demands for power at different times of the year, day or week. Likewise, the need for VSDs differs according to the process.



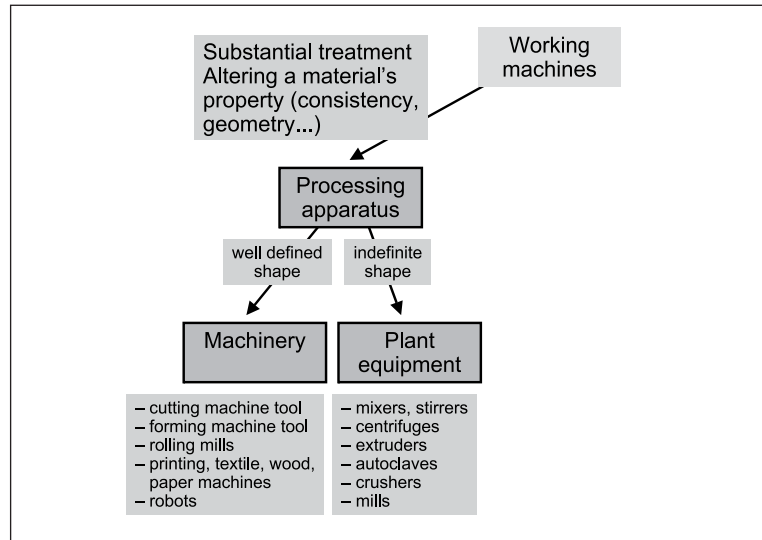
## Variables in processing systems

This diagram shows what kinds of variables affect the processing system. These variables can be divided into energy and material variables. In the processing system itself, material or energy is processed by means of mechanical power, electromagnetic influence, thermal influence, chemical and biological reactions or even nuclear power.

Each process needs the material and energy supplied to accomplish the required process. The product or final material state is the output of the process, but in every process, waste, in the form of energy and/or material, is also produced.

In processing systems, VSDs are used to control the mechanical power of the different machines involved in the process.

Material treatment can also be controlled by VSDs. A good example is a drying kiln, in which the hot air temperature must be constant. The process is controlled by controlling the speed of the hot air fans using VSDs.



## Machines are used to alter materials' properties...

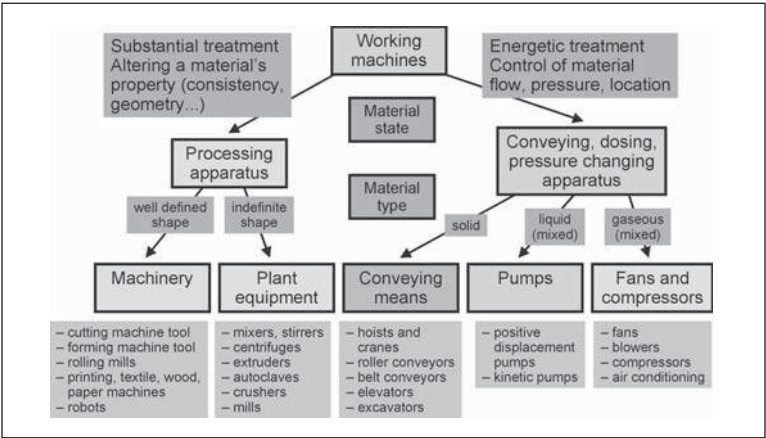
As mentioned earlier in this guide, working machine processes can be divided into two categories. The first category is material treatment, which is accomplished using various types of processing apparatus to alter a material's properties into another form.

### Well defined shape

Processing apparatus can be divided into two groups according to the resulting shape of the material being treated. The shape can be either well defined or indefinite. Materials with a well-defined shape, such as paper, metal and wood, are processed with machinery. Examples are paper machines, rolling mills and saw mill lines.

### Indefinite shape

Materials with an indefinite shape, such as various food products, plastics etc., are processed with plant equipment. Examples of this kind of equipment are margarine stirrers, and different kinds of centrifuges and extruders.



...and to transport materials

The second category consists of machines which transport material to a desired location. This group consists of conveying, dosing and pressure changing apparatus. These machines can be divided into three different sub-groups according to whether the type of material being treated is a solid, liquid or gas.

Solid materials

Solid materials, such as shipping containers, metal, wood, minerals and of course people, are transported by conveying apparatus. Such apparatus includes cranes, conveyors and elevators.

Liquid materials

Liquid materials, for example, water, oil or liquid chemicals, are transported by pumps.

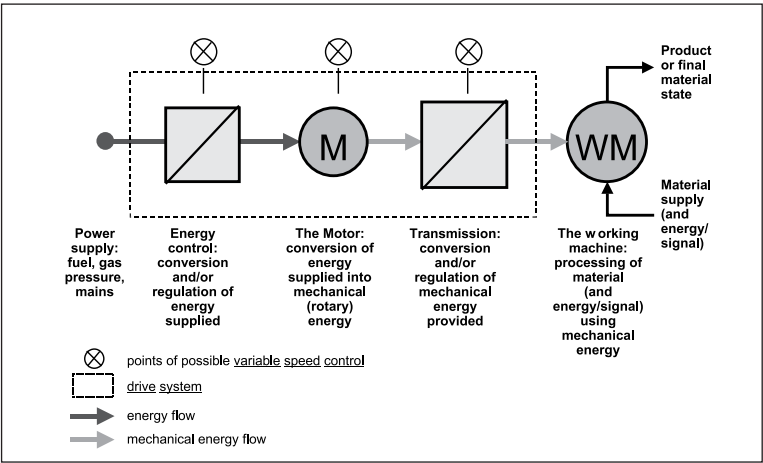
Gaseous materials

Gaseous materials such as air are transported using fans, compressors or blowers. A special application of these machines is air conditioning.

In the diagram above, five different types of machines are presented. They either shape or transport different types of material, but all of them can be potentially used with Variable Speed Drives.

# Chapter 3 - The workhorse of industry: the electric motor

All of the machines mentioned earlier in this guide are commonly driven by electric motors. It can be said that the electric motor is the workhorse of industrial processes. In this chapter, we will take a closer look at electrical motors - especially the squirrel cage AC motor, which is the most common motor used in industrial processes.

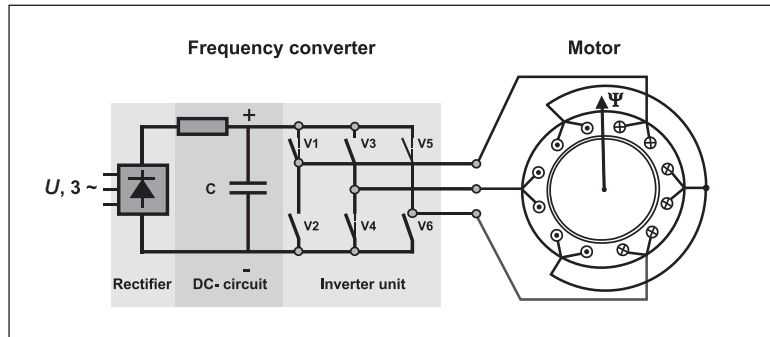


## Electric motors drive most machines

Every machine consists of four different components, shown in the diagram. These components are energy control, the motor, transmission and the working machine. Together, the first three components comprise the so called “drive system”. This drive system can transform a given type of energy, usually electrical, into mechanical energy, which is then used by the working machine. Energy is supplied to the drive system from the power supply.

In each of the three drive system components, variable speed control is possible. Variable speed control can be accomplished, for example, using a frequency converter as the energy control component, a two speed motor as the motor component and gears as the transmission component.

As mentioned earlier, most machines are driven by an electric motor. Electric motors can be divided into AC and DC motors. AC motors, particularly squirrel cage motors, are the most commonly used motors in industrial processes.



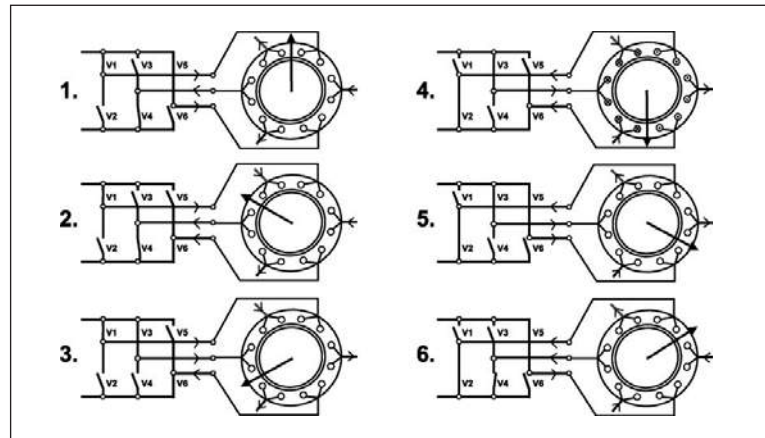
## Motors convert electrical energy into mechanical energy

An AC motor's ability to convert electrical energy into mechanical energy is based on electromagnetic induction. The voltage in stator windings forms the current and magnetic flux. The direction of this flux can be determined using the right hand rule from the stator current.

By changing the direction of the voltage in stator windings, the direction of the flux can also be changed. By changing the voltage direction in the three phase motor windings in the correct order, the magnetic flux of the motor starts to rotate. The motor's rotor will then follow this flux with a certain slip. This is the basic principle used to control AC motors.

This control can be achieved using a frequency converter. As the name suggests, a frequency converter changes the frequency of the alternating current and voltage. A frequency converter consists of three parts. Regular 50 Hz 3-phase current is fed in to the rectifier part, which converts it to direct current. The DC voltage is fed into the DC bus circuit, which filters the pulsating voltage. The inverter unit then connects each motor phase either to the negative or the positive DC bus according to a certain order.

To receive the flux direction shown in the diagram, switches  $V1$ ,  $V4$  and  $V5$  should be closed. To make the flux rotate counterclockwise, switch  $V6$  has to be closed but  $V5$  has to be open. If switch  $V5$  is not opened, the circuit will short circuit. The flux has turned  $60^\circ$  counterclockwise.



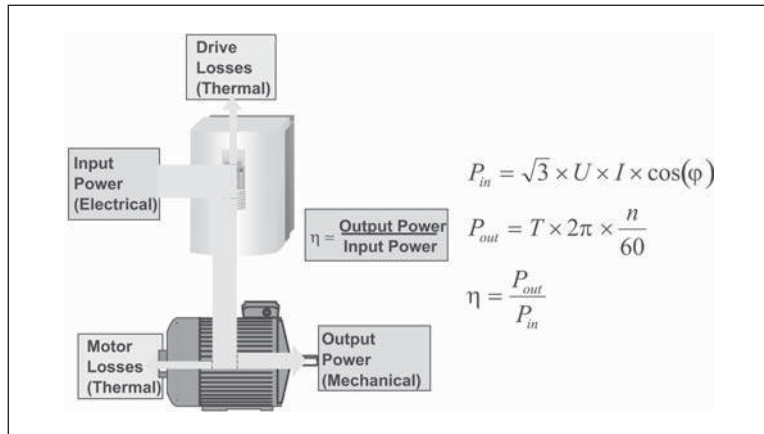
## Frequency converters control electromagnetic induction

There are eight different switching positions in the inverter. In two positions, the voltage is zero, ie, when all the phases are connected to the same DC bus, either negative or positive. So in the remaining six switching positions there is voltage in the motor windings, and this voltage creates magnetic flux.

The diagram shows these six switching positions and the flux directions, which the voltage in the windings generates in each case. Voltage also generates current in the windings, the directions of which are marked with arrows in each phase.

In practice, control is not quite as simple as presented here. Magnetic flux generates currents in the rotor. These rotor currents complicate the situation. External interference, such as temperature or load changes, can also cause some control difficulties. Nevertheless, with today's technology and know-how, it is possible to effectively deal with interference.

Electrical VSDs also provide many additional benefits, such as energy savings, because the motor does not use more electrical energy than required. Furthermore, control is better than with conventional methods, because electrical VSDs also provide the possibility for stepless control.



## The efficiency of the drive system

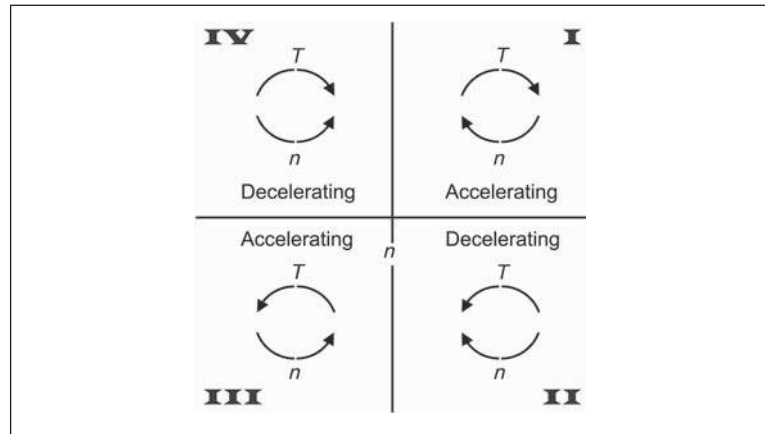
The total efficiency of the drive system depends on the losses in the motor and its control. Both drive and motor losses are thermal, so they appear as heat. Input power to the drive system is electrical in form, while output power is mechanical. That is why calculating the coefficient of efficiency ( $\eta$ ) requires knowledge of both electrical and mechanical engineering.

Electrical input power  $P_{in}$  depends on voltage ( $U$ ), current ( $I$ ) and the power factor ( $\cos\phi$ ). The power factor tells us what proportion of the total electric power is active power and how much is so called reactive power. To produce the required mechanical power, active power is required. Reactive power is needed to produce magnetisation in the motor.

Mechanical output power  $P_{out}$  depends on the required torque ( $T$ ) and rotating speed ( $n$ ). The greater the speed or torque required, the greater the power required. This has a direct effect on how much power the drive system draws from the electrical supply. As mentioned earlier, the frequency converter regulates the voltage, which is fed to the motor, and in this way directly controls the power used in the motor as well as in the process being controlled.

Electrical switching with transistors is very efficient, so the efficiency of the frequency converter is very high, from 0.97 to 0.99. Motor efficiency is typically between 0.82 and 0.97 depending on the motor size and its rated speed. So it can be said that the total efficiency of the drive system is always above 0.8 when controlled by a frequency converter.





## Reversed rotation or torque is sometimes required

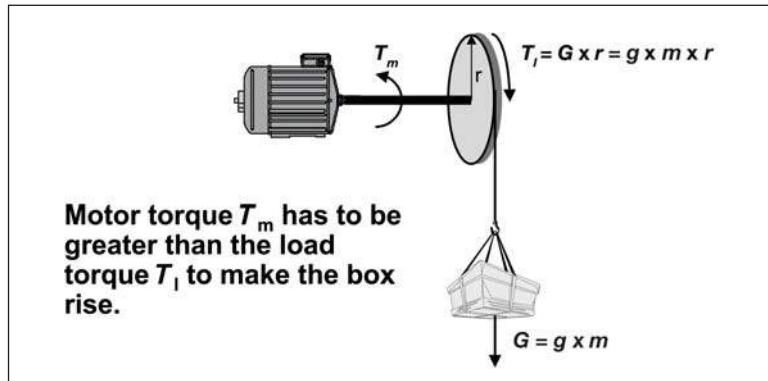
In some cases, reversed rotation of the motor is required. In addition, torque direction requirements might change. These factors combined form the so called “four quadrant drive”. The name comes from the four different quadrants (I to IV) shown in the diagram.

**I quadrant:** In the first quadrant, the motor is rotating clockwise. Because the torque is in the same direction as the speed, the drive is accelerating.

**II quadrant:** In the second quadrant, the motor is still rotating clockwise, but the torque is in the opposite direction, so the drive is decelerating.

**III & IV quadrants:** In the third and fourth quadrant, the motor is rotating counterclockwise and the drive is again accelerating or decelerating, depending on the torque direction.

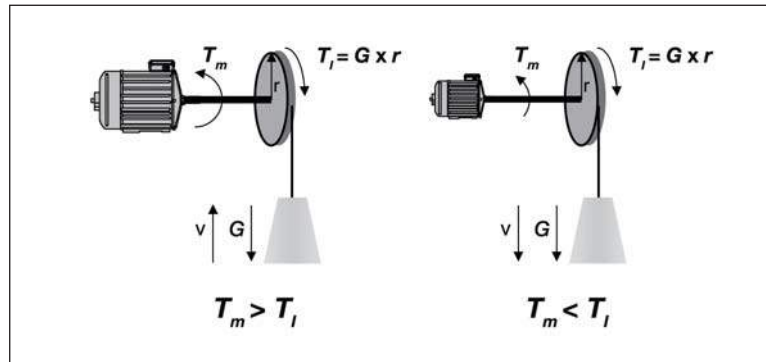
With a frequency converter, torque direction changes can be implemented independent of the direction of rotation. To produce an efficient four quadrant drive, some kind of braking arrangement is required. This kind of torque control is especially required in crane applications, where the rotation direction might change, but the torque direction remains the same.



The load, friction and inertia resist rotation

The motor must produce the required torque to overcome the load torque. Load torque consists of friction, inertia of the moving parts and the load itself, which depends on the application. In the example in the diagram, the motor torque has to be greater than the load torque, which is dependent on the mass of the box, if the box is to rise.

Load factors change according to the application. For example, in a crusher, the load torque is dependent not only on friction and inertia, but also on the hardness of the crushed material. In fans and blowers, air pressure changes affect the load torque, and so on.



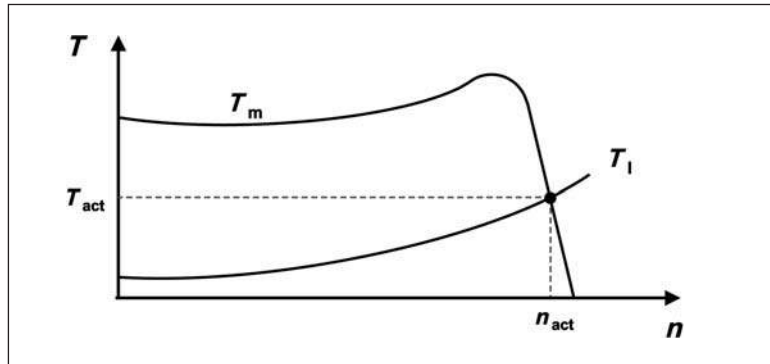
The motor has to overcome the loading torque

In any case, the loading torque has to be known before selecting the motor for the application. The required speed also has to be known. Only then can a suitable motor be selected for the application.

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If the motor is too small, the requirements cannot be met and this might lead to serious problems. For example, in crane applications, a motor that is too small may not be able to lift the required load quickly enough to the desired height. It might even drop the load completely, as shown in the diagram. This could be disastrous for people working at the harbour or site where this crane would be used. To calculate the rated torque of the motor the following formula can be used:

$$T[Nm] = 9550 \times \frac{P[kW]}{n[1/min]}$$



The drive torque and load torque are equal at nominal speed

A motor's torque/speed curve is unique and has to be calculated for every motor type separately. A typical torque/speed curve is shown in the graph as  $T_m$ . As can be seen, the maximum load torque is reached just below nominal speed.

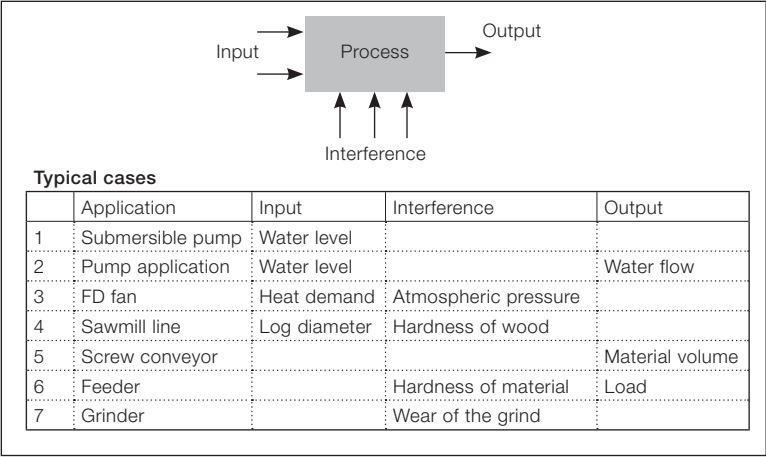
Load torque  $T_l$  usually increases with speed. Depending on the application it can be linear or quadratic. The motor will automatically accelerate until the load torque and motor torque are equal. This point is shown on the graph as the intersection of  $T_m$  and  $T_l$ . Actual torque ( $T_{act}$ ) is shown on the y-axis and actual speed ( $n_{act}$ ) on the x-axis.

These are the principles that govern how an ordinary squirrel cage motor works. With a frequency converter, optimal control performance can be obtained from the motor and the whole drive system. This will be introduced later in this guide.

# Chapter 4 - Variable volumes require some form of control

In most processes there is at least one variable. This variable causes the need for process adjustment. Therefore variable processes and material volumes need some form of control.

In this chapter we will look at processes and their variables. We will also examine different control methods.

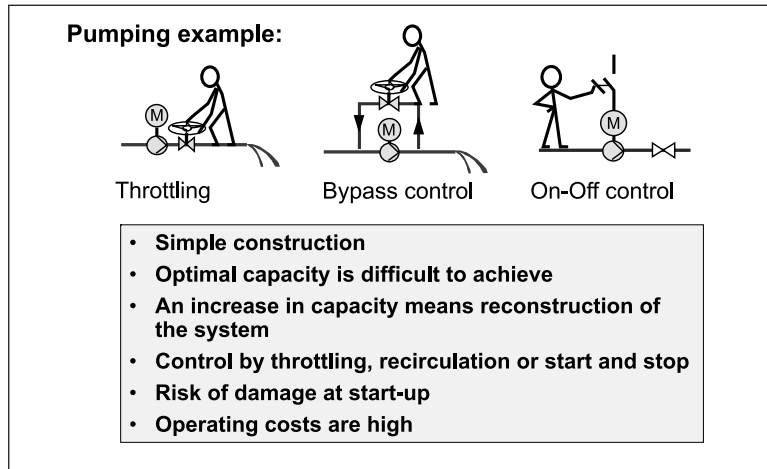


## Variable material flow and input/output requirements

There may be many different parameters involved in a process, the most common being input, output and interference. These parameters may need to be constant or they may need to be changed according to a preset pattern. As discussed in the first chapter, there are always inputs and outputs present in a process and, in almost every case, interference as well.

In some processes there is no interference and the input is constant. This kind of process works without any variable speed control. However, if the output parameters need to be changed, the input is variable or there is interference present, then variable speed control might be the solution to fulfilling the process requirements.

The above table lists some processes in which variable speed control is required. It also shows the reasons for the control; input, interference or output.



## Simpler control methods

There are many simpler control methods in existence such as throttling or bypass control. The construction of such equipment is usually very simple and the investment may look cost effective at first.

However, there are many drawbacks. For example the optimal process capacity, which gives the best quality of the process, is very difficult to achieve with simple control. An increase in production capacity usually requires reconstruction of the whole process and with each direct on-line startup there is a risk of electrical and/or mechanical damage.

The simple control methods are also energy consuming, so in addition to the total operating cost being higher than with VSDs, the environmental effects, such as CO<sub>2</sub> emissions from power plants, also increase. Therefore, the total life-cycle cost of investment in simple control methods is much higher than with VSDs.



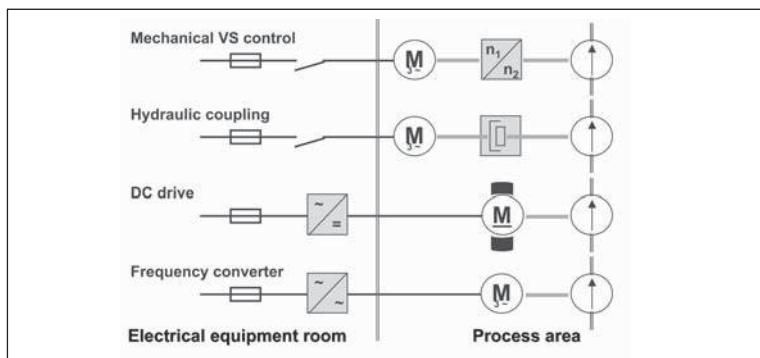
The best control method is VSD

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The best control method for most systems is VSD. Imagine you are driving a car for example. If you are driving on a highway and entering a populated area, you need to reduce speed so that you don't risk your own and other peoples' lives.

The best possible way to do this is of course to reduce motor rotation speed by taking your foot off the gas pedal and, if necessary, changing to a lower gear. Another possibility would be to use the same gear, keep your foot on the gas and reduce speed simply by braking. This would not only cause wear on the engine and brakes, but also use a lot of fuel and reduce your overall control of the vehicle. Furthermore, the original goal of reducing speed without risking your own and other peoples' lives would not have been achieved.

Variable volumes require some form of control



## Mechanical, hydraulic and electrical VSDs

Above are the four most common VSDs in the industrial sector. Mechanical variable speed control usually uses belt drives, and is controlled by moving conical pulleys manually or with positioning motors.

### Hydraulic coupling

In hydraulic coupling, the turbine principle is used. By changing the volume of oil in the coupling, the speed difference between the driving and driven shafts changes. The oil amount is controlled with pumps and valves.

### DC drive

In the DC drive, a DC converter changes the motor supply voltage fed to the DC motor. In the motor, a mechanical inverter, a commutator, changes direct current to alternating current.

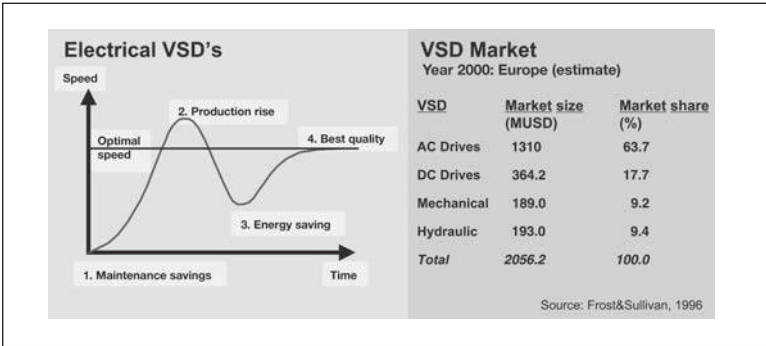
### AC drive

In the frequency converter or AC drive, a standard squirrel cage motor is used, so no mechanical inverters are required. The speed of the motor is regulated by a frequency converter that changes the frequency of the motor voltage, as presented earlier in this guide. The frequency converter itself is controlled with electrical signals.

The diagram shows the location of the control equipment for each type of VSD. In mechanical and hydraulic VSDs, the control equipment is located between the motor and the working machine, which makes maintenance very difficult.

In electrical VSDs, all control systems are situated in an electrical equipment room and only the driving motor is in the process area. This is just one benefit of electrical VSDs. Other benefits are presented on the following page.





## Electrical VSDs dominate the market

Here are the four most important arguments for using electrical VSDs, presented along with estimated VSD market shares in Europe in 2000. The four main benefits of using electrical VSDs are highlighted at the turning points of the speed curve.

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### Maintenance costs

Direct on-line starting stresses the motor and also the electrical equipment. With electrical VSDs, smooth starting is possible and this has a direct effect on maintenance costs.

### Productivity

Process equipment is usually designed to cater for future productivity increases. Changing constant-speed equipment to provide higher production volumes requires money and time. With the AC drive, speed increases of 5 to 20 percent are not a problem, and the production increase can be achieved without any extra investment.

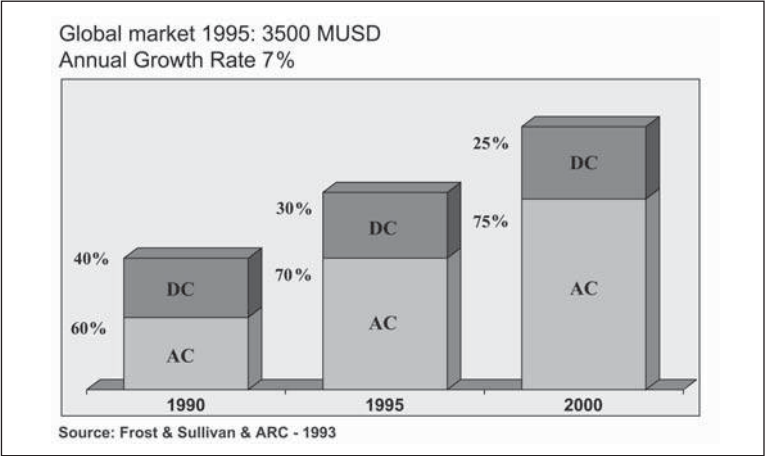
### Energy saving

In many processes, production volumes change. Changing production volumes by mechanical means is usually very inefficient. With electrical VSDs, changing the production volume can be achieved by changing the motor speed. This saves a lot of energy particularly in pump and fan applications, because the shaft power is proportional to the flow rate to the power of three.

### Higher quality

The accurate speed control obtainable with electrical VSDs results in process optimization. The optimal process control leads to the best quality end product, which means the best profit for the customer.

Due to these benefits, electrical VSDs are dominating the market, as can be seen from the table above. AC and DC drives together account for over 75 percent, and AC drives for more than 50 percent, of the total VSD market in Europe in 2000.



The AC drives market is growing fast

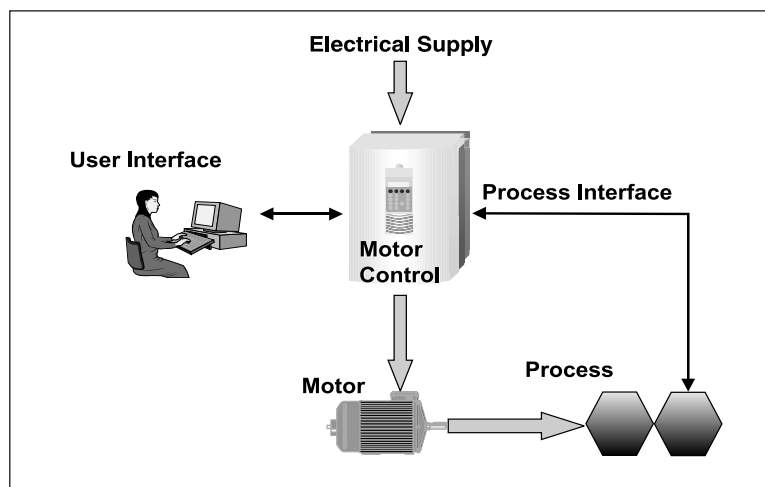
This diagram shows the projected development of the electrical VSDs market to the year 2000. As can be seen, the AC drives market is growing at almost 10 percent per year, which accounts for the entire growth of the electrical and VSD market. The market share of DC drives is diminishing, and the total DC market size remains approximately constant. This progress is due to the development of AC drives technology.

As presented earlier in this guide, the AC drive has many benefits over other process control methods. The difference between the AC and the DC motor is that the DC motor has a mechanical commutator, utilising carbon brushes. These brushes need regular maintenance and the commutator itself complicates the motor structure and consumes energy. These are the main reasons why the AC drives market share is growing in comparison to DC drives.

## Chapter 5 - AC drive: the leading control method

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Taking into account everything presented so far, we can confidently say that the AC drive is the leading control method. In the following chapter we will take a closer look at the different features of the AC drive, and the levels of performance the drive can offer.



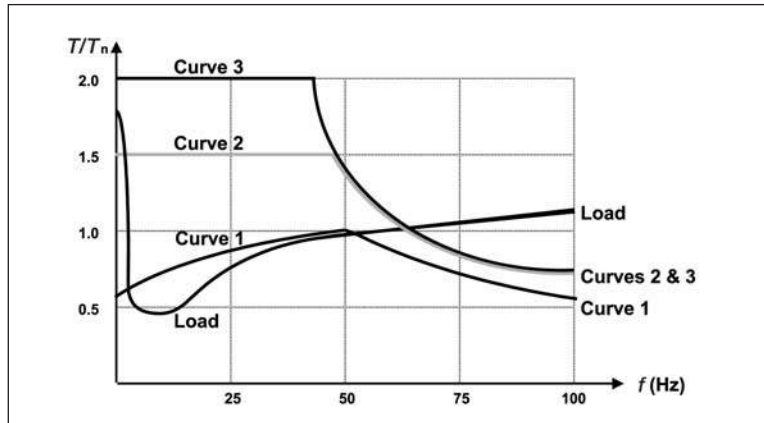
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### The basic functions of an AC drive

In this diagram, the basic functions of an AC drive are presented. There are four different components in AC drive motor control. These components are the user interface, the motor, the electrical supply and the process interface.

An electrical supply feeds the required electricity to the drive; one selection criteria for the drive is the supply voltage and its frequency. The AC drive converts the frequency and voltage and feeds the motor. This conversion process is controlled by signals from the process or user via the process and user interfaces.

The user interface provides the ability to observe the AC drive and obtain different process information via the drive. This makes the drive easy to integrate with other process control equipment and overriding process control systems.



### A motor's load capacity curves with an AC drive

If the motor is driven without a frequency converter, its load capacity curves cannot be modified. It will produce a specified torque at certain speed and maximum torque cannot be exceeded.

With a frequency converter drive, there are different loading options. The standard curve, Curve 1 in the diagram, can be used continuously. Other curves can only be used for certain periods of time, because the motor's cooling system is not designed for this kind of heavy use.

These higher load capacity levels might be needed, for example, during startup. In certain applications, as much as twice the amount of torque is required when starting. With a frequency converter this is possible, meaning that a motor can be dimensioned according to its normal use. This reduces the investment cost.

To be able to use these features it is very important that the load, the AC drive and the motor are compatible. Otherwise the motor or the converter will overheat and be damaged.

**Important features:**

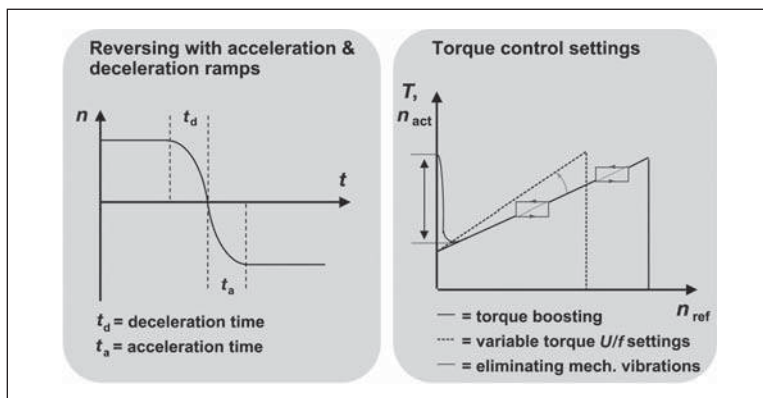
- inputs and outputs
- reversing function
- ramp times acceleration/deceleration
- variable torque V/Hz settings
- torque boosting
- eliminating mechanical vibrations
- load limits to prevent nuisance faults
- power loss ride-through
- stall function
- slip compensation
- flying start

## AC drive features for better process control

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AC drives also have other internal features and functions which are sometimes required for better process control. Examples of these features are listed in the diagram. With inputs and outputs for example, different kinds of process information can be fed to the drive and it will control the motor accordingly. Alternatively, the load can be limited to prevent nuisance faults and to protect the working machine and the whole drive system.

In the following sections the listed features are presented in more detail.



### Reversing

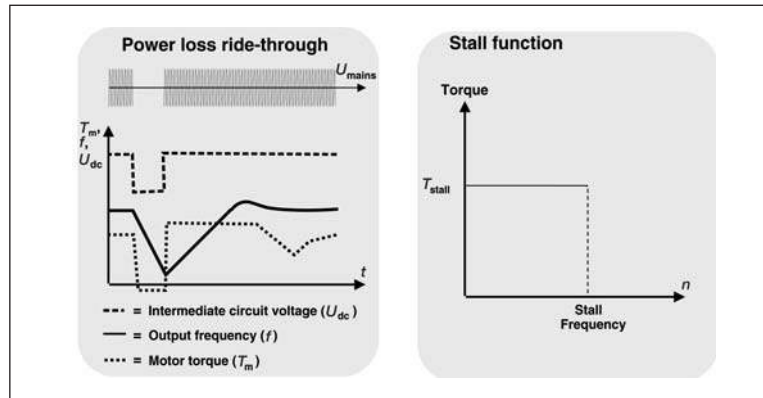
Reversing the motor rotation is simple to accomplish with an AC drive. With ABB's frequency converters it can be achieved simply by pressing one button. Furthermore, it is possible to set different acceleration and deceleration ramp times. The ramp form can also be modified according to the user's wishes. In the diagram (above, left) an S-ramp has been presented. Another possibility could be a linear ramp.

### Torque control

Torque control is relatively simple with an AC drive. Torque boosting, which was presented earlier, is necessary if a very high starting torque is required. Variable torque  $U/f$  settings mean that maximum torque can be achieved at a lower speed of rotation than normal.

### Eliminating mechanical vibrations

Mechanical vibrations can be eliminated by by-passing critical speeds. This means that when a motor is accelerated close to its critical speed, the drive will not allow the actual speed of the motor to follow the reference speed. When the critical point has been passed, the motor will return to the regular curve very quickly and pass the critical speed.



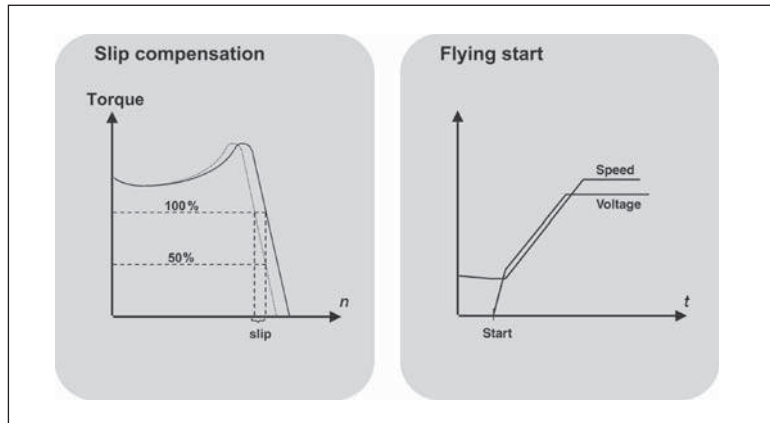
### Power loss ride-through

The power loss ride-through function is used if the incoming supply voltage is cut off. In such a situation, the AC drive will continue to operate using the kinetic energy of the rotating motor. The drive will be fully operational as long as the motor rotates and generates energy for the drive.

### Stall function

With an AC drive, the motor can be protected in a stall situation with the stall function. It is possible to adjust supervision limits and choose how the drive reacts to the motor stall condition. Protection is activated if three conditions are met at the same time.

1. The drive frequency has to be below the preset stall frequency.
2. The motor torque has to rise to a certain limit, calculated by the drive software.
3. The final condition is that the motor has been in the stall limit for longer than the time period set by the user.



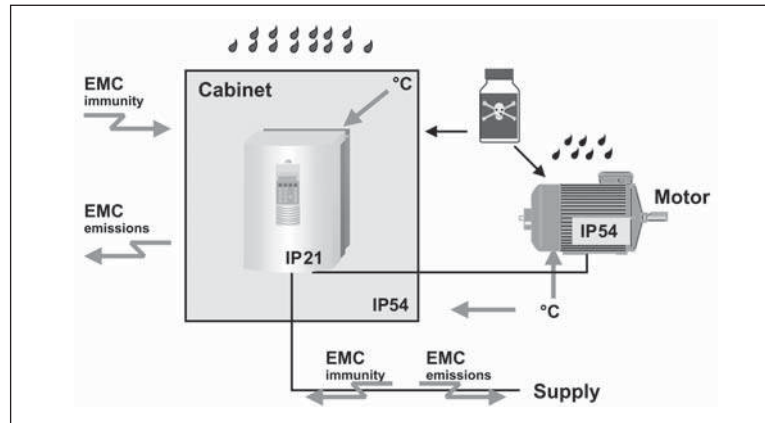
### Slip compensation

If the motor load torque is increased, the speed of the motor will decrease as shown in the diagram (above, left). To compensate for this slip, the torque/speed curve can be modified with the frequency converter so that torque increase can be accomplished with the same speed as previously.

### Flying start

The flying start feature is used when a motor is connected to a flywheel or a high inertia load. The flying start works even without a speed feedback. In case of rotating motor, the inverter is first started with a reduced voltage and then synchronised to the rotating rotor. After synchronised the voltage and the speed are increased to the corresponding levels.





## Environmental features

Any drive system has to handle different environmental stresses such as moisture or electrical disturbances. The squirrel cage motor is very compact and can be used in very hostile conditions. The IP54 degree of protection guarantees that it can work in a dusty environment and that it can bear sprinkling water from any direction.

The frequency converter usually has an IP21 degree of protection. This means that it is not possible to touch the live parts and that vertically dripping water will not cause any harm. If a higher degree of protection is required, it can be obtained, for example, by installing the drive inside a cabinet with the required degree of protection. In such cases, it is essential to ensure that the temperature inside the cabinet will not exceed the allowed limits.

## EMC

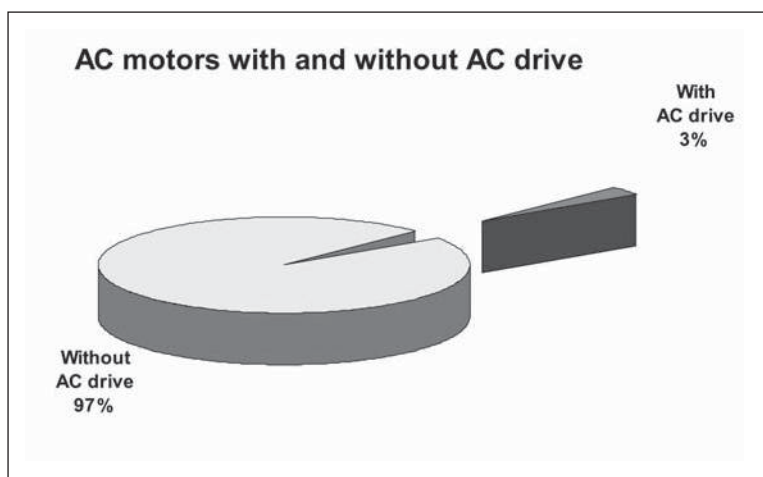
Another important environmental feature is electromagnetic compatibility (EMC). It is very important that a drive system fulfills the EMC directives of the European Union. This means that the drive system can bear conductive and radiative disturbances, and that it does not send any conductive or radiative disturbances itself either to the electrical supply or the surrounding environment.

If you require more information about the EMC directives and their effects on drives, please refer to ABB's Technical guide No. 3, EMC Compliant Installation and Configuration for a Power Drive System.

## Chapter 6 - Cost benefits of AC drives

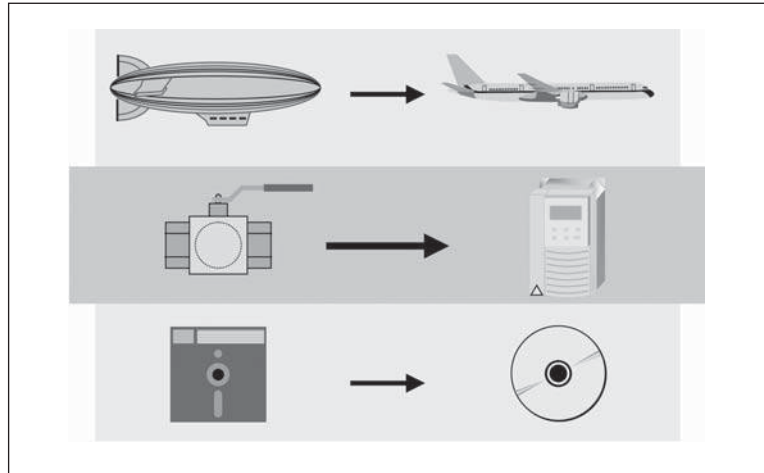
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In addition to their technical advantages, AC drives also provide many cost benefits. In this chapter, these benefits are reviewed, with the costs divided into investment, installation and operational costs.



At the moment there are still plenty of motors sold without variable speed AC drives. This pie chart shows how many motors below 2.2 kW are sold with frequency converters, and how many without. Only 3 percent of motors in this power range are sold each year with a frequency converter; 97 percent are sold without an AC drive.

This is astonishing considering what we have seen so far in this guide. Even more so after closer study of the costs of an AC drive compared to conventional control methods. But first let's review AC drive technology compared to other control methods.



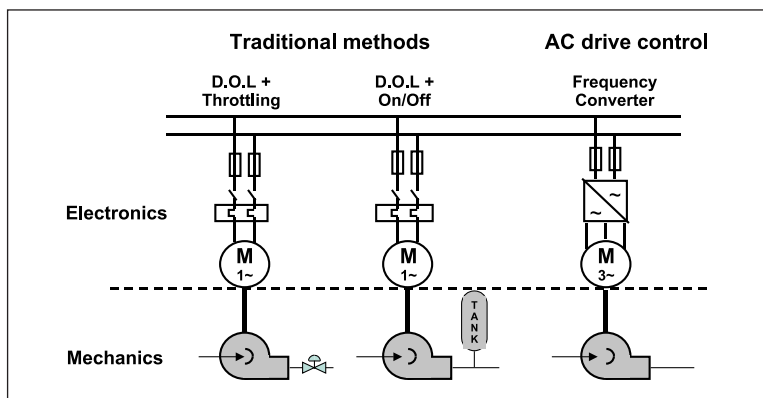
## Technical differences between other systems and AC drives

4

AC drive technology is completely different from other, simpler control methods. It can be compared, for example, to the difference between a zeppelin and a modern airplane.

We could also compare AC drive technology to the development from a floppy disk to a CD-ROM. Although it is a simpler information storage method, a floppy disk can only handle a small fraction of the information that a CD-ROM can.

The benefits of both these innovations are generally well known. Similarly, AC drive technology is based on a totally different technology to earlier control methods. In this guide, we have presented the benefits of the AC drive compared to simpler control methods.



## No mechanical control parts needed

To make a proper cost comparison, we need to study the configurations of different control methods. Here we have used pumping as an example. In traditional methods, there is always a mechanical part and an electrical part.

In throttling you need fuses, contactors and reactors on the electrical side and valves on the mechanical side. In On/Off control, the same electrical components are needed, as well as a pressure tank on the mechanical side. The AC drive provides a new solution. No mechanics are needed, because all control is already on the electrical side.

Another benefit, when thinking about cost, is that with an AC drive we can use a regular 3-phase motor, which is much cheaper than the single phase motors used in other control methods. We can still use 220 V single phase supply, when speaking of power below 2.2 kW.

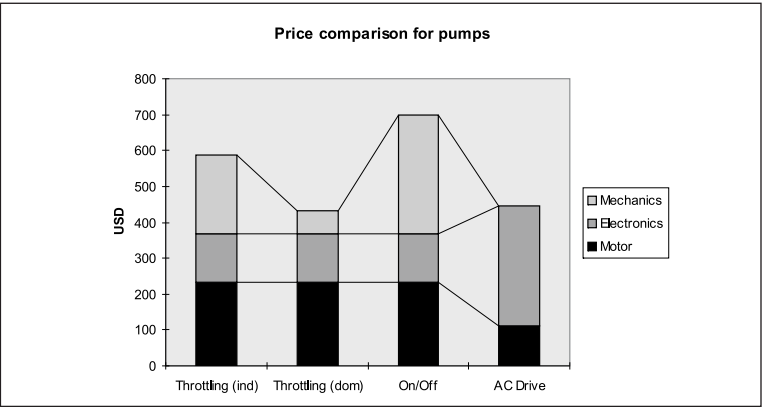
Conventional methods:	AC drive:
both electrical and mechanical parts	all in one
many electrical parts	only one electrical component
mechanical parts need regular maintenance	no mechanical parts, no wear and tear
mechanical control is energy consuming	saves energy

### Factors affecting cost

This list compares the features of conventional control methods with those of the AC drive, as well as their effect on costs. In conventional methods there are both electrical and mechanical components, which usually have to be purchased separately. The costs are usually higher than if everything could be purchased at once.

Furthermore, mechanical parts wear out quickly. This directly affects maintenance costs and in the long run, maintenance is a very important cost item. In conventional methods there are also many electrical components. The installation cost is at least doubled when there are several different types of components rather than only one.

And last but not least, mechanical control is very energy consuming, while AC drives practically save energy. This not only helps reduce costs, but also helps minimise environmental impact by reducing emissions from power plants.



### Investment costs: mechanical and electrical components

In this graph, the investment structure as well as the total price of each pump control method is presented. Only the pump itself is not added to the costs because its price is the same regardless of whether it's used with an AC drive or valves. In throttling, there are two possibilities depending on whether the pump is used in industrial or domestic use. In an industrial environment there are stricter requirements for valves and this increases costs.

#### The motor

As can be seen, the motor is much more expensive for traditional control methods than for the AC drive. This is due to the 3-phase motor used with the AC drive and the single phase motor used in other control methods.

#### The AC drive

The AC drive does not need any mechanical parts, which reduces costs dramatically. Mechanical parts themselves are almost always less costly than a frequency converter, but electrical parts also need to be added to the total investment cost.

After taking all costs into account, an AC drive is almost always the most economical investment, when compared to different control methods. Only throttling in domestic use is as low cost as the AC drive. These are not the total costs, however. Together with investment costs we need to look at installation and operational costs.

	Throttling	AC drive
Installation material	20 USD	10 USD
Installation work	5h x 65 USD = 325 USD	1h x 65 USD = 65 USD
Commissioning work	1h x 65 USD = 65 USD	1h x 65 USD = 65 USD
Total	410 USD	140 USD
<b>Savings in installation: 270 USD!</b>		

Installation costs: throttling compared to AC drive

Because throttling is the second lowest investment after the AC drive, we will compare its installation and operating costs to the cost of the AC drive. As mentioned earlier, in throttling there are both electrical and mechanical components. This means twice the amount of installation material is needed.

Installation work is also at least doubled in throttling compared to the AC drive. To install a mechanical valve into a pipe is not that simple and this increases installation time. To have a mechanical valve ready for use usually requires five hours compared to one hour for the AC drive. Multiply this by the hourly rate charged by a skilled installer to get the total installation cost.

The commissioning of a throttling-based system does not usually require more time than commissioning an AC drive based system. One hour is usually the time required in both cases. So now we can summarise the total installation costs. As you can see, the AC drive saves up to USD 270 per installation. So even if the throttling investment costs were lower than the price of a single phase motor (approximately USD 200), the AC drive would pay for itself before it has even worked a second.

	Throttling	AC drive saving 50 percent
Power required	0.75 kW	0.37 kW
Annual energy 4000 hours/year	3000 kWh	1500 kWh
Annual energy cost with 0.1 USD/kWh	300 USD	150 USD
Maintenance/year	40 USD	5 USD
Total cost/year	340 USD	155 USD
<b>Savings in one year: 185 USD!</b>		

Operational costs: maintenance and drive energy

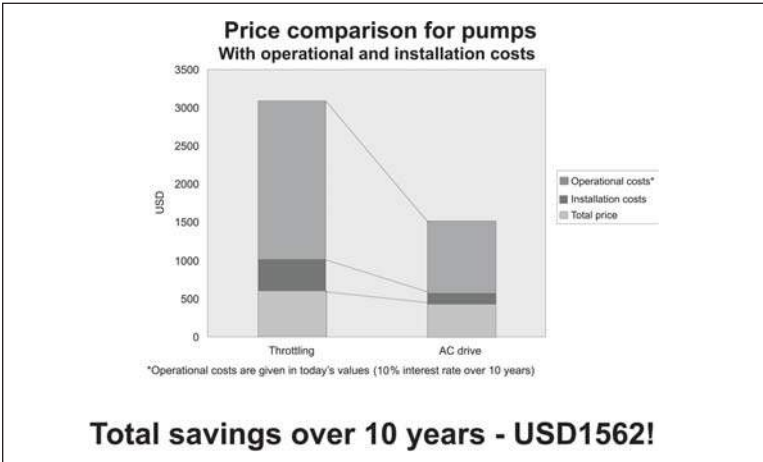
In many surveys and experiments it has been proved that a 50 percent energy saving is easily achieved with an AC drive. This means that where power requirements with throttling would be 0.75 kW, with the AC drive it would be 0.37 kW. If a pump is used 4000 hours per year, throttling would need 3000 kWh and the AC drive 1500 kWh of energy per year.

To calculate the savings, we need to multiply the energy consumption by the energy price, which varies depending on the country. Here USD 0.1 per kWh has been used.

As mentioned earlier, mechanical parts wear a lot and this is why they need regular maintenance. It has been estimated that whereas throttling requires USD 40 per year for service, maintenance costs for an AC drive would be USD 5. In many cases however, there is no maintenance required for a frequency converter.

Therefore, the total savings in operating costs would be USD 185, which is approximately half of the frequency converter’s price for this power range. This means that the payback time of the frequency converter is two years. So it is worth considering that instead of yearly service for an old valve it might be more profitable to change the whole system to an AC drive based control. To retrofit an existing throttling system the pay-back time is two years.





Total cost comparison

In the above figure, all the costs have been summarised. The usual time for an operational cost calculation for this kind of investment is 10 years. Here the operational costs are rated to the present value with a 10 percent interest rate.

In the long run, the conventional method will be more than twice as expensive as a frequency converter. Most of the savings with the AC drive come from the operational costs, and especially from the energy savings. It is in the installation that the highest individual savings can be achieved, and these savings are realised as soon as the drive is installed.

Taking the total cost figure into account, it is very difficult to understand why only 3 percent of motors sold have a frequency converter. In this guide we have tried to present the benefits of the AC drive and why we at ABB think that it is absolutely the best possible way to control your process.

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