The workhorse and its jockey

Combined with electric motors of any power rating, ABB's AC drives are winning the race in terms of energy efficiency and process control

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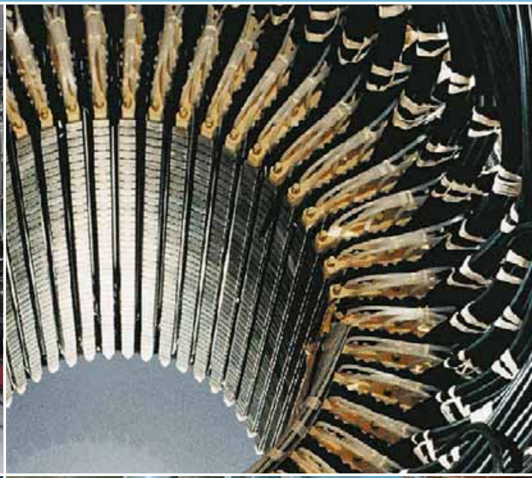
An estimated 65 percent of electrical energy is used by electric motors, the workhorse of modern industry. Even though these motors efficiently convert electrical energy into mechanical energy, some 20 percent of this is lost by wasteful throttling mechanisms in many industrial processes. Powering the process according to demand significantly reduces the amount of energy consumed. Even a small reduction in motor speed would make a huge difference, and the most effective method of controlling a motor's speed is through the use of AC drives.

Advances in technology, in particular in the area of power electronics, have resulted in the use of AC drives with motors whose power ratings range from 100 Watts to 100 Megawatts. Because of this wide range, client discussions nowadays tend to focus more on the functional requirements of their application, many of which are satisfied using a drive's embedded intelligent controller. These controllers enable a wide range of application-segment-specific solutions, ranging from pump applications to demanding metal rolling mill solutions.



Electric motors are, quite literally, the driving force behind all automation systems used in industry, commerce and buildings. In fact, motors consume around 65 percent of all the electrical energy produced in the world. There are two types of electric motor, AC and DC, and about three-quarters of all motors power pumps, fans or compressors. Industrial processes tend to use AC motors, particularly squirrel cage motors. However, when connected directly to the power grid, an AC motor by design will run at a fixed speed. To regulate the amount of energy consumed, the motor generally requires some kind of variable-speed control.

Variable speed is accomplished by placing the motor under the control of an AC drive, also called a variable-speed drive or an adjustable-speed drive. These drives are used in a wide range of applications in many industries, such as cement, chemical, pulp and paper, metal, and oil and gas. For example, in power plants and in the chemical industry, motors need to be adjusted according to the main process, which changes due to varying power demands at different times of the day, week or year.

AC drives are ideal in such a case because they follow demand with high efficiency. In fact, they can cut a company's energy bill by up to 60 percent! According to an ABB study, the use of medium-voltage AC drives in the speed control of pumps, fans and compressors has the potential to deliver global savings of 227 TWh per year [1]. This is equal to the annual output of 144 fossil-fuel-type power plants[1)], or equivalent to the total energy consumption in Spain.

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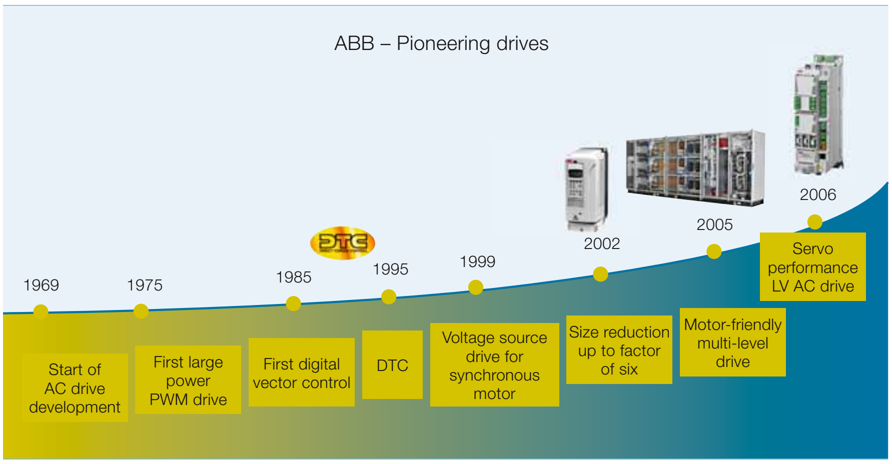
With an estimated 16 percent of the global market, ABB is the number one supplier of variable-speed drives 1. Its drives product portfolio covers all motors with a broad range of embedded control functionality and with power ratings from 100 Watts to 100 Megawatts. To enhance its drives even further, ABB engineers have carefully selected key technologies from the academic and industrial field of power electronics. Each technology has been adapted and extended way and above the application requirements. For example, the power conversion circuit found throughout the product range is based on the so-called voltage-source inverter technology, and the high performance motor control strategy, direct torque control (DTC) is applied to low-voltage induction motors as well as to medium-voltage synchronous motors.

Thanks to technological developments, drive manufacturers have been able to add attractive features to increase the functionality of their products. With its strong background in process automation, ABB has been able to focus particularly on embedding specific application control features. For example, ABB drives not only control speed according to an external reference, but they can relate their actions to the load of the motor. In addition, these drives are able to compensate for elasticity in the mechanics, dampen oscillations, autonomously coordinate action with other drives or even supervise auxiliary equipment.

1 For over 40 years, ABB has been at the forefront of drives technology.



Converting electrical energy

AC motor control – or the ability to convert electrical energy into mechanical energy – is based on the principle of electromagnetic induction. The voltage in the stator windings forms the current and magnetic flux, and changing the direction of this voltage causes the direction of the flux to also change. If the voltage direction in the windings of a three-phase motor is changed in the correct order, the magnetic flux of the motor starts to rotate. The motor's rotor will then follow this rotating flux. This control can be achieved using a frequency converter, which in principle, changes the frequency and amplitude of the normally fixed network voltage.

In practice, however, AC motor control is slightly more intricate. Rotor currents, generated by magnetic flux, complicate the situation. Additionally, external interferences, such as temperature or load changes, can also create control difficulties. Nevertheless, with today's technology and know-how, it is possible to effectively deal with these interferences.

ABB's modern AC drives are all based on the same basic circuit, the voltage-source inverter. It consists of a rectifier, a DC-bus circuit and an inverter unit 2. The rectifier converts a regular 50 Hz three-phase current into a DC current that is fed into the DC-bus circuit. This circuit then filters out the pulsating voltage, thus establishing a DC voltage. The proceeding inverter unit inverts this voltage into an AC

Footnote

1) Assuming an average plant produces 350 MW for 4,500 hours/year.

voltage with variable frequency and amplitude. It does this by essentially connecting each motor phase either to the positive or negative DC bus, according to a specific sequence in time. The sequence is determined by an embedded intelligent motor control system.

The inverter shown in 2 is the basic two (voltage) level inverter circuit. It is the most optimal solution for AC voltages up to 1 kV. To reach higher voltages, this circuit is extended by cleverly combining the same base circuit. For example, in the medium-voltage range, three level inverter circuits have become standard during the past decade. Recently, ABB has increased the maximum achievable output voltage of its frequency converters with a new design in which the motor terminals may be switched to five different voltage levels. This innovation, which perfects the output waveshape and boosts reliability, was realized by drawing largely on proven concepts and components [2].

Whatever combination of the basic circuit is used, ABB's high performance control scheme, DTC, determines the switching sequence. Thanks to an electronic mirror image of the motor, the embedded controller always knows the present state of rotation. Because the controller is able to maintain a kind of "street map" of the above-mentioned voltage directions, it knows exactly which "highways and byways" the converter circuit needs to take in order to continue turning the motor. The benefits of this to the user of ABB drives are many but in a nutshell, he is guaranteed seamless integration across the whole power range of products.

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Simpler variable speed methods

At present – if the entire power range available is considered – less than ten percent of all motors sold every year are equipped with frequency converters, despite them being the least maintenance-intensive means of variable-speed control available. The benefits of controlling the energy input to a process by means of a frequency converter outweigh the more conventional and simpler methods in existence, such as throttling or bypass control 3. The construction of such equipment is usually very simple and the investment may, at first glance, seem cost effective. However, there are many drawbacks. To begin with, optimal process capacity is very difficult to achieve with simple control. An increase in production capacity usually requires reconstruction of the entire process.

Not only are total operating costs much higher but throttling and bypass control, simply put, are energy wasters. Imagine trying to regulate the speed of your car by keeping one foot on the accelerator and the other on the brake. Running a motor at full speed while throttling the output has the same effect; part of the produced output immediately goes to waste. In fact, so much energy is wasted by inefficient constant speed and mechanical control mechanisms that every industrialized nation around the world could make several power stations redundant simply by using speed control.

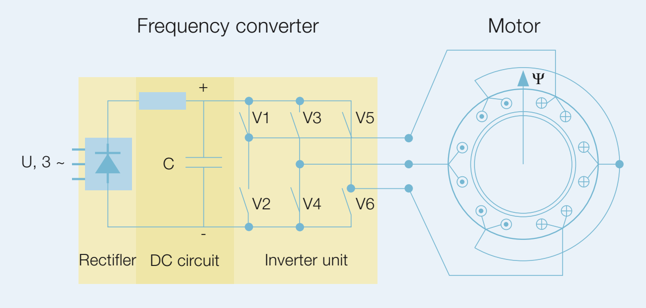
If the motor is driven without a frequency converter, its load capacity curves cannot be modified. The motor will produce a specified torque at certain speed and maximum torque cannot be exceeded. If a higher load capacity is needed for start-up, then the motor needs to be over-dimensioned.

More to a drive than meets the eye

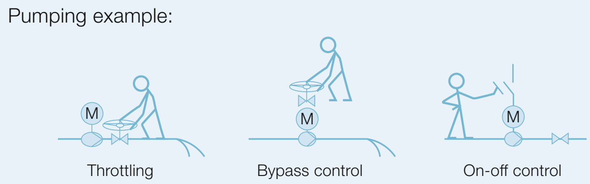
Apart from their role as variable-speed controllers, AC drives have other internal features and functions, which are sometimes required for better process control. These include:

- Inputs and outputs for supervision and control signals
- A reversing function
- Ramp time acceleration/deceleration
- Variable torque voltage/frequency settings
- Torque boosting
- Mechanical vibration elimination
- Load limits to prevent nuisance faults
- Power loss ride-through
- Stall function
- Slip compensation
- Flying start

2 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° counterclockwise.



3 Simple control methods: imperfect control and a waste of energy



- Simple construcion
- Optimal capacity is difficult to achieve
- An increase in capacity means reconstruction of the system
- Control by throttling, recirculation or start and stop
- Risk of damage at startup
- Operating costs are high

These and many more functions facilitate the use of drives in many different applications. With decades of experience in process control, ABB has developed functions that help the user determine the correct reference speed for the process and to efficiently eliminate disturbances. These functions stretch across the whole power range of ABB drives. So no matter the size of the drive or the application, saving energy has never been easier!

Evolving technologies

Technological developments have helped lower the price of variable-speed drives, making them an economical alternative to mechanical methods of speed control. As many technologies continue to evolve, research and development teams continue to work on making drives even smaller and more affordable. But it is not only size that matters. Engineers and scientists are designing drives that are more intelligent, have better communications and are easier to install and control. Such drives will open the door to many new applications.

The ACS800-02 drive, available in the 90 to 150 kW power range, is only one-sixth the size of comparable drives from other manufacturers.

Over the next 10 years, a combination of tighter semi-conductor and mechanical part integration will lead to even fewer parts within a drive.

ABB predicts that over the next 10 years, a combination of tighter semiconductor and mechanical part integration will lead to even fewer parts within a drive. Fewer parts mean fewer interfaces and fewer mechanical fixings, and this means improved reliability.

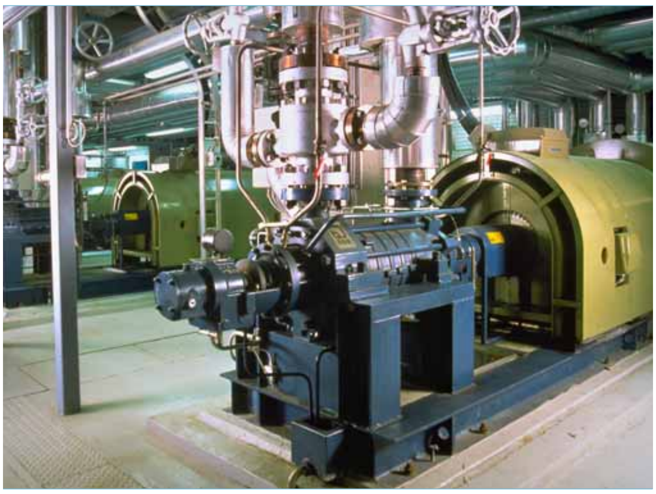
Take, for example, the solid state switches, which are the key components inside a frequency converter 2. They are completely realized in a thin rectangular silicon chip (about 1 to 2 cm^2) or a round silicon wafer, which has a diameter of between 3 and 10 cm. The chip is controlled via an electrical auxiliary input on one side, which defines whether it is blocking voltage between the top and bottom side (like an open mechanical contact), or whether it will conduct current through the silicon from one side to the other (like a closed mechanical contact). Integrating all the auxiliary electronics turns the solid state switch into an electronic building block with ideal behavior that can be combined into any circuit.

Controlling this combination of silicon switches, which is achieved using processors, is as easy as sending data to a printer. At the same time, the processors are able to supervise the electrical motor, observe and control the mechanical load, or send and receive data from an external automation system.

The development of power semiconductors is an important factor that influences the future of variable-speed drives, but so too is the technology used for cooling. Even though air-cooling is likely to remain the dominant technique, a considerable amount of research and development is being invested in developing new cooling techniques. For example, developments in numerical modeling mean that advanced computer flow modeling techniques are used to design heat sinks that achieve more effective cooling. Scientists are also looking at new materials, the idea of integrating a heat sink with the power module for better cooling performance, and improving fan performance with variable-speed control.

Clean water pumps at a water plant

A feed pump at a combined cycle power station



The biggest and smallest ABB drives – the ACS5000 at 2.2 m high and 6.5 m wide a and the ACS55 b

Liquid cooling is finding increasing use in wind power, transportation, marine applications and applications in dusty or humid environments.

One notable technological development is ABB's motor control platform, DTC. Launched about 14 years ago, DTC continues to be the main control platform for ABB drives. Current research is focusing on the use of computational simulation to predict future motor behavior with the aim of:

- Further increasing the efficiency of the power conversion process
- Strengthening robustness against disturbances
- Improving motor diagnostics

DTC's very high performance is also being exploited for new applications with demanding motion control requirements.

Hot metal on the conveyor – part of a continuous casting machine

Drives and communication

Drives have benefited from the growth of Ethernet communications by becoming an integral part of control, maintenance and monitoring systems. Taking advantage of Ethernet's wide bandwidth, these intelligent drives are able to communicate greater amounts of monitoring information. In addition to this type of information, the drive can also collect data that describes the state of the process being controlled.

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Furthermore, ABB's award winning DriveMonitor™ analyzes the data immediately, starts additional logging of data if necessary and informs the operator with clear text messages about the present status of the drive. A detailed analysis of this data can be used to adjust the process and improve productivity. It could also be used to increase process availability through proactive fault management and asset optimization.

Overall, the future looks good for ABB's AC drives. With the continuous increase in efficiency and power handling capability, ABB's variable-speed drives are able to control electrical AC motors over a power range from 100 W to 100 MW. Innovation is rapidly spreading across the entire power range so that in the very near future, the industrial world can choose from an even more unique and exclusive product offering.

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[1] **Wikstroem, P., Tolvananen, J., Savolainen, A., Barbosa, P.** Saving energy through power efficiency. *ABB Review* 2/2007, 73–80.

[2] **Jörg, P., Scheuer, G., Wikström, P.** A higher level of efficiency. *ABB Review* 4/2007, 26–31.

Further reading

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