

Driving towards a better future

Fact: ABB's electronic variable-speed drives are major energy savers, environmentally friendly and a wise investment

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With an estimated 65% of industrial electrical energy used by electric motors, it is no wonder that major users in industry increasingly see energy reduction as a key to improving their profitability and competitiveness. Because variable-speed drives reduce energy consumption while increasing productivity, they can, depending on the application, pay for themselves within a few months.

As well as being a cost issue, energy efficiency is also an environmental one. With legislation in place in Europe to curb CO₂ emissions, industry is searching for technologies that can help reduce emission levels. It is estimated that ABB drives installed around the world during the past 12 years reduce global CO₂ emissions by about 68 million tonnes every year. This is a little less than the emissions of a country the size of Finland, with a population of over five million people.

In the past, energy consumption was rarely a priority for an engineering team. Whether it was in industries such as cement, chemical, pulp and paper, metal, and oil and gas, the focus was primarily on technology and the ability of automation systems to increase productivity.

Nowadays, industrial companies and utilities are faced with a growing list of concerns including increasing customer demands on efficiency and quality, the environment, increased competition and the maintenance of quality standards. How then is a company supposed to meet these demands, and at the same time cut production costs?

One of the answers lies in reduced energy consumption and in particular, energy consumption by electric motors which can be reduced in two main ways – efficient control of the speed at which they operate (using variable speed drives), and making the motors themselves more efficient.

Induction motors – the driving force behind industry

The alternating current (AC) induction motor was invented by Nicola Tesla more than a century ago. Motors are the prime movers behind most industrial machines including pumps, fans, compressors, conveyors, cranes and mixers and because of their robustness, simple design and low maintenance requirements induction motors have remained the de facto workhorse in industry today.

Before the advent of electronic AC variable-speed control, mechanical solutions (throttling valves, and gears or belt drives) were used to match motor output to process demand at any given moment. These were not only complex in design but they also wasted a considerable amount of energy. Since the 1970s, it has been possible to replace these traditional control methods such as throttling valves with AC drives.

Even though electric motors are responsible for consuming perhaps the greatest part of industrial electricity – an estimat-

ed 65% – around the world [1], this does not necessarily mean that electric motors are an example of bad engineering. Quite the contrary in fact, when one considers that the efficiency of modern electric motors is approximately twice that of the best combustion engines. It is the large number of electric motors in industry and their huge powering units that make the aggregated energy demand enormous.

It's all about speed control

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 pump's output has the same effect: a part of the produced output immediately goes to waste. Yet this is still one of the most common control methods used in industry.

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 AC drives and high-efficiency motors.

Much can be achieved by designing and using machines with low unit losses but it is not component efficiency alone that determines the energy efficiency of a process. It is most important that the process itself is well designed and that it is operated in an efficient manner. By controlling the motor speed, matching process demand and machine output becomes possible. This is the key to efficient and 'lean' production practices in processes that require any work input in the form of rotating power.

Control methods for a pumping system

In pump and fan applications, using variable-speed drives can cut energy consumption by as much as two-thirds

1. A pump or fan running at half speed

1 Variable speed AC drives enable energy-efficient flow control in pumps, fans and compressors.



Following an energy appraisal, the saving potential can be calculated using ABB software tools.

consumes only one-eighth of the energy compared to one running at full speed. The traditional way of controlling the flow through a pump is by using a throttling valve. This valve is much like the water tap in the home: a fully open tap provides full water flow and decreased water pipe pressure.

Pump performance is usually expressed in terms of flow, Q, and pressure (head), H. For a typical centrifugal pump, the maximum head value occurs when the resistance in the pipes is so high that it forces the pump to reach its 'shut off head'. At 'shut off head', the flow rate through the pump is zero. The maximum head is mainly determined

ABB drives installed around the world during the past 12 years reduce global CO₂ emissions by an estimated 68 million tonnes per year.

by the outside diameter of the pump's impeller and the speed of the rotating shaft. The head will change as the capacity of the pump is altered.

The operating point of a pump is a balance between the resistance in the pipes and the work done by the pump. Therefore an increase in resistance forces the pump to generate more pressure, resulting in decreased fluid flow

through the system. But energy efficiency becomes the casualty in this scenario and the example below will show why.

Pump input power [1] in certain operating conditions is given by:

$$P = \frac{\rho \times Q \times H \times g}{\eta} \text{ where}$$

- P = power required by the pump
- ρ = (rho), density of the fluid.
- Q = volume flow through the pump
- H = head (pressure) produced by the pump
- g = gravitational acceleration constant
- η = pump efficiency

One can assume that density ρ and gravitational acceleration remain constant. By also assuming that pump efficiency, η , remains constant, the equation above is simplified to

$$P = k \times Q \times H$$

where k is a coefficient representing the combined effect of the constants.

It can now be seen that the product $Q \times H$ is directly proportional to the power needed [2].

Suppose the flow through the pump is to be reduced by 30%. Assume the pump flow and head pressure is 10 units at the nominal operating point. The new operating point, with 30% less flow, is therefore equal to a flow of 7 units. The new head value is given in [2] as 12.7 units. Multiplying these

results in a total of 89 units, which in this example, represents the power consumption for throttling control.

Another method of flow control is by means of an AC drive which regulates the frequency fed to the motor driving the pump, thereby altering the speed of the pump.

As in the first example, the flow needed is 70% of the original. With reference to [3], the operating point moves via a so-called system curve which represents the resistance in the piping system. The power needed to operate the pump in this new operating range is (from the colored area) only 45 units.

In these examples, motor efficiency compensation and AC drive efficiency compensation must be accounted for. Because the same motor can be used in both cases, its effect in total power consumption is equal. In the speed-controlled example however, AC drive losses of typically two to three percent at nominal power must be added. But even with these losses, the energy efficiency obtained using variable speed drives is by far superior. A small reduction in speed can make a big difference in the energy consumption, and as many pump systems run at less than full capacity a lot of the time, a variable speed drive can produce huge savings.

The Affinity laws [1] of a centrifugal pump (or fan) express the effect on the capacity, head and power consumption

of the pump due to different speeds and geometric similarity. To be more specific, the power required to run a pump is proportional to the cube of the speed. This means that if 100% flow requires full power, 75% requires $(0.75)^3 = 42\%$ of full power and 50% flow requires 12.5% of the power.

Capacity control methods in fans

Similar laws of fluid mechanics apply to fan theory, with the only difference being that the fluid 'pumped' is, unlike water, compressible.

[4] shows the electric power consumption of a fan at different volume flow levels and with different control methods:

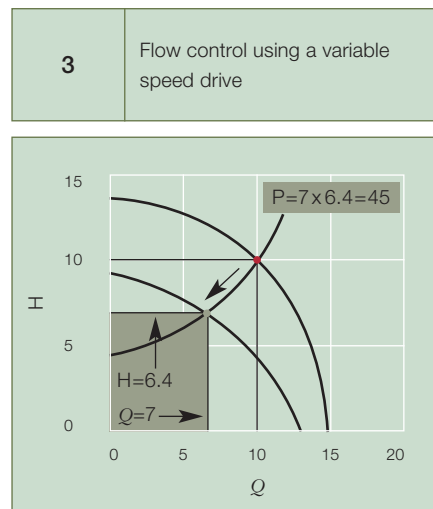
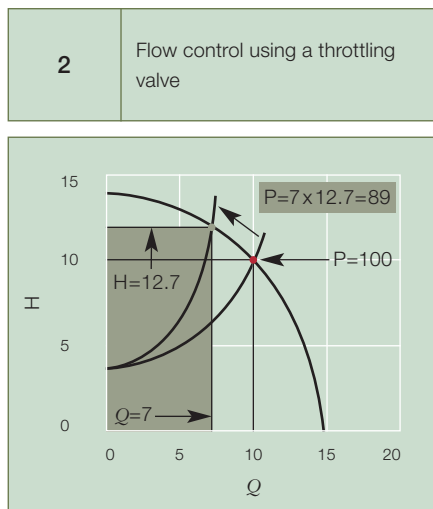
1. Theoretical minimum power (lossless fan air power in speed control)
2. Speed control using an AC drive
3. Axial flow fan; pitch angle adjustment
4. Centrifugal fan; inlet vane control
5. Centrifugal fan; damper control; B-type impeller
6. Axial-flow fan damper control.

The lower the curve (ie, when the curve is far away from the horizontal axis, the power consumption is high which is bad. If the curve is at a low level or close to the axis, power demand is low, which is good), the better the energy efficiency, and as with pumps, speed control comes out on top.

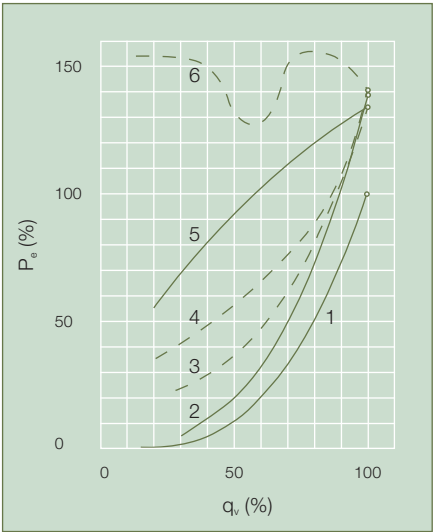
Saving potential

In an electrical grid system, there must be a balance between the supply (power plants) and demand (end-users) at all times. Because the total efficiency of the energy chain from a power plant fuel depot to a process pump is very low (due to various losses along the way), a conscientious consumer can not only be responsible for substantial fuel savings at the power plant but also create a positive environmental effect.

It is clear that by utilizing high-efficiency motors and variable-speed AC drives the potential for huge energy savings and less negative environmental impact is substantial. A recent study [2] by the European copper institute showed that, per annum, an electricity saving potential of some 200 TWh (billion kWh) ex-



4 Electric power consumption of a fan at different volume flow values and control methods



ists. This translates into a reduction of 100 million tonnes of CO₂ emissions [3] from industries in the European Union! ABB is doing its part, as the next section will illustrate.

Estimated savings already achieved with ABB AC drives

The installed base of ABB's AC drives is roughly equal to the deliveries of the last dozen years. Knowing the number of units and their power ratings delivered each year [4], ABB can estimate, with reasonable accuracy, the total delivered AC drive capacity.

The aggregated nominal electric power of AC drives delivered between 1992 and 2003 [5] is equal to 46,200 MVA. A reasonable assumption is that 50% of this capacity, or 23,100 MVA, was used in pump and fan applications. An average power saving of 50% (11,550 MVA \approx 11,550 MW) means the rotating speed must be reduced by approximately 25%. If the average operating time was 7,000 hours per year (pumps and fans in process industries often run continuously), the reduced electricity consumption equals 80,850 GWh (7,000 h \times 11,550 MW) per year worldwide. This is equivalent to a reduction in CO₂ emissions (emission factor [6] used is 0.84 kgCO₂-eq/kWh) of 67.9 Mega tonnes:

The conclusion is that that a total of more than 1.5 million ABB AC drives delivered during the last 12 years have reduced global CO₂ emissions by almost 68 million tonnes per annum.

Potential savings still achievable by utilizing drives technology

Suppose variable speed drives technology was used in all possible applications around the world, what then would the approximate global energy saving potential be?

The MCP is one of a series of energy-saving initiatives under the European climate change programme and ABB holds Endorser status.

Around the world, 15,500 TWh of electricity is generated per annum [7]. Industry is responsible for 41.7%, or 6,500 TWh, of the total. If it is assumed that 65% of 6,500 TWh powers industrial motor drive systems, this is equivalent to a consumption of 4,200 TWh. A small portion of AC motors (say 5%) is already speed-controlled. If it is estimated that an additional 25% (1,000 TWh) of this energy is used by motors that would clearly benefit from speed control and the average energy saving was 50%, the total energy saving potential is

approximately 500 TWh or 3.2% of the world's electricity generation.

Depending on the baseline methodology and the CO₂ emission factor (eg, 0.5–0.84 kgCO₂-eq/kWh) used, this saving potential translates into 250–420 million tons of avoided CO₂ emissions.

This analysis, if only a rough estimate, nevertheless demonstrates the order of magnitude of CO₂ emissions that can be reduced if AC drives were used in all viable motor applications.

Energy efficiency and productivity

The premium in productivity that results from intelligent speed control can be utilized in two ways:

- To increase productivity
- Keeping production stable while reducing energy consumption.

In both cases, the energy consumption per unit is reduced compared to the earlier situation.

Case UK: Boliden MKM

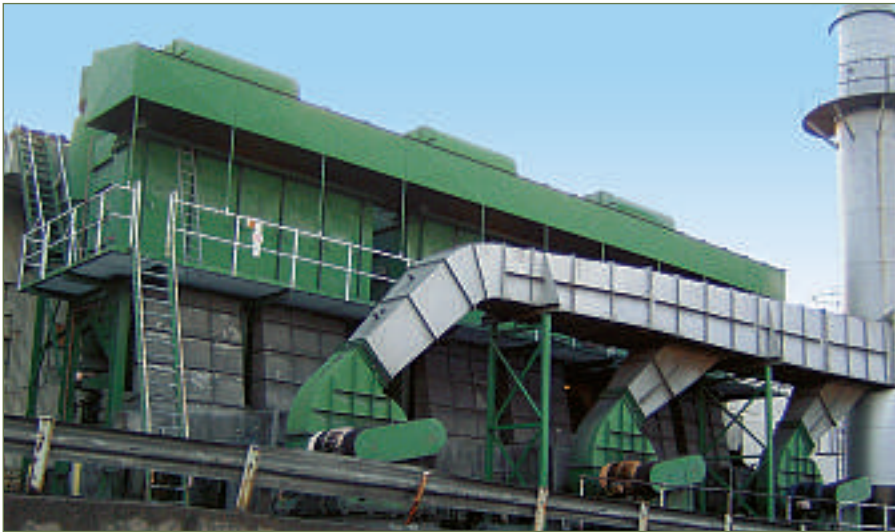
Central Electrical, one of ABB's channel partners in the UK, carried out an ener-



Variable-speed drives offer the most effective method of controlling a motor's speed, thereby contributing significantly to energy saving.

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Installing variable speed drives from ABB on the filtration plant will help Boliden MKM save £ 130,000 per year in energy at its brass casting plant near Walsall, UK.



gy audit on filtration plants belonging to Boliden MKM (a leading manufacturer of brass and copper products) by measuring the energy use during a typical production week. The audit mainly covered the fume extraction filter plant for the brass casting process, which consists of two Luhrfilter filtration plants, one with a 250 kW fan and the other with three 132 kW fans [5]. The airflow from the fans was controlled using dampers as restrictors.

The results pointed to potential energy savings with ABB drives of at least £ 25,000 (US \$44,650) a year for the 250 kW fan and £ 15,000 (US \$26,800) a year for each of three smaller fans – a saving of £ 70,000 (US \$125,000) a year and a payback period of just 9 months. In any case, the total savings achieved from the installation proved to be much higher, some £ 130,000 (US \$232,200), a

figure verified by Boliden's own energy measurement system.

In addition to direct energy savings, AC drives can be used to upgrade existing production machinery. Cantex is a leading producer of PVC (polyvinyl chloride) pipes in the US. At one of its plant's in Reno, Nevada, Cantex upgraded two of 18 extrusion lines at the plant with ABB's ACS 800 adjustable speed direct torque control drives. This extruder retrofit increased production by at least 30% .

ABB and The EU's Motor Challenge Program

In 2003, the European Commission introduced a voluntary program known as The Motor Challenge Program (MCP) in which industrial companies are given help to improve the energy efficiency of their motor driven systems. Companies

can participate as partners or endorsers. Partners are typically manufacturing companies that use motor-driven systems. Endorsers are manufacturers of motor-driven system components. ABB has become an official Endorser of the MCP.

The MCP is one of a series of energy-saving initiatives under the European climate change programme. MCP officials estimate that the replacement of all inefficient EFF3 classed motors now in use across Europe with standard efficiency EFF2 versions would yield energy savings of 6 TWh or 300 million Euros. The use of EFF1 class motors would yield even higher savings, but the greatest saving potential of all comes if more variable speed AC drives were used to control these motors.

Most plants – whether factories or utilities – have ample opportunities for saving energy and increasing productivity. It is just a matter of finding the applications, quantifying the potential and starting to save. In many cases, an investment in a variable speed drive will enable payback in less than a year.

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References

- [1] Europump & Hydraulic Institute: Variable speed pumping – a guide to successful applications. Elsevier Ltd 2004. p.41, equations (2) and (3).
- [2] European Copper Institute: Energy Efficient Motor Drive Systems, April 2004.
- [3] Average CO₂ emission per unit electricity, estimated to be 0.5 kg/kWh on an average electricity generation mix in this study (source: IEA).
- [4] ABB Review, Special Report: Motors and drives. May 2004. p. 5.
- [5] Data with author.
- [6] To be able to calculate avoided CO₂ emissions, so-called emission factors are used. They refer to the generation-weighted average emissions per electricity unit, and can be defined in different ways: baseline, operating margin, build margin, combined etc. The approach selected here is operating margin, which means that all low- operating cost, 'must-run' power plants are excluded. The energy saving at the demand side (= motors) is compensated by reduced condensing power generation by a mix of fossil fuels (coal, gas, oil) in the system. The value used is 0.84 kgCO₂-eq/kWh.
- [7] http://www.iea.org/Textbase/stats/electricitydata.asp?country=World&SubmitA=Submit&COUNTRY_LONG_NAME=World.