Improving motor efficiency for a better environment

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Energy efficiency has never been higher on the agenda than it is today. As fossil fuels diminish and more people become aware of the correlation between wasting energy and environmental damage, the need to reduce energy consumption will concern an increasingly broader section of the community. In the front line will be politicians, many of whom have committed their countries to meeting the targets laid down at the Rio Earth Summit as well as those enshrined in the Kyoto agreement. The Kyoto agreement commits the signatories to reduce emissions of CO_2 and other greenhouse gases to 1990 levels by 2000. As electricity production accounts for 30 percent of man-made emissions of this greenhouse gas, meeting these commitments is conditional on reducing electrical energy consumption.

Governments have never been more serious about reducing the environmental impact of energy use. A raft of new legislation has been brought in to try to stem the amount of energy that goes from the producer to the consumer, and hence to the environment, without doing useful work in between.

The cost of this energy is also concerning major energy users in industry, who increasingly see energy use reduction as a key to

1 *Major energy consumers, such as chemical plants and refineries, are looking to the efficient use of electric motors to keep them competitive.*

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

3 *Drives can contribute to large energy savings that will have a positive effect on the world's environment. This is most true of pump and fan applications, the most common applications for motors.*

improving their profitability in an increasingly competitive world 1.

An estimated 65% of industrial energy is used by electric motors, and so they are an obvious target for attention. Energy consumption by electric motors can be reduced in two main ways – efficient control of the speed at which they run, and making the motors themselves more efficient. Design and production of motors and the drives that control them are both areas of expertise for ABB Automation, and we clearly have a responsibility to bring this expertise to bear in an effort to reduce the environmental impact that motors have.

Optimum motor speed brings best efficiency

By far the most effective method of controlling a motor's speed is through the use of variable speed drives 2. However, much control is still performed with throttling valves in pump systems or vanes in fan applications, while the demands for rotating machinery are solved by gears or belt drives. Speed control with belt drives, gearboxes and hydraulic couplings all add to the inefficiency of the system to varying degrees, and require the motor to run at full speed all of the time. In addition, mechanical drives can be noisy as well as difficult to service, situated as they are between the motor and the driven machinery. These arrangements often seem cost-effective at first sight, but they are energy wasters.

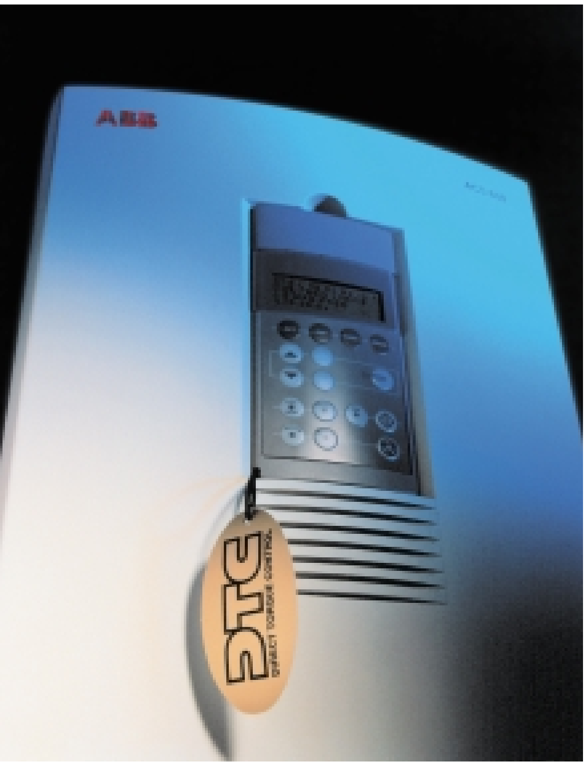
Imagine trying to regulate the speed of your car by keeping one foot on the accelerator and the other on the brake. Running a motor at full speed while throttling the output has the same effect; a part of the produced output immediately goes to waste. Of that estimated 65% of industrial energy used by electric motors, some 20% is lost by wasteful throttling mechanisms.

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 variable speed drives instead. In the right applications, variable speed drives can make a huge difference.

In pump and fan applications 3, using variable speed drives can cut the energy bill by as much as 60%. A pump or fan running at half speed consumes only one-eighth of the energy compared to one running at full speed. Or, put differently: the power required to run a pump or a fan is proportional to the cube of the speed. This means that if 100 percent flow requires full power, 75 percent requires $(0.75)^3$ = 42 percent of full power, and 50 percent flow requires $(0.5)^3$ = 12.5 percent of the power.

As a small reduction in speed can make a big difference in the energy consumption, and as many fan and pump systems run at less than full capacity a lot of the time, a variable speed drive can produce huge savings. This is particularly so when compared to a motor that is continuously running at full speed.

The efficiency of motors and drives has improved considerably over the years. Motors have improved in efficiency by an average of 3% over the last decade, while ABB AC drives delivered in the past ten years for the speed control of pumps and fans are estimated to reduce electricity consumption by about 30,000 GWh per year worldwide. This means that ABB AC drives now in use reduce global CO_2 emissions by over 25 million tonnes every year, equivalent to the emissions of a city the size of Berlin, with a population of over three million people.



4 ***DTC is a new drive control method that can produce dramatic energy savings compared to conventional control methods.***

If we replace an average 1980s motor and frequency converter with an ABB high-efficiency motor and an ACS 600 drive, the payback time due to lower energy consumption is two to four years, depending on annual operating hours and energy price. This points to a great potential replacement market as users seek to improve their energy consumption.

And when an 11-kW motor drive is replaced, annual CO_2 emissions are reduced by six tonnes! To this end, from the middle of this year, ABB will sell standard motors from 11 kW upward only in the best efficiency class defined by the EU, something our competitors will find hard to match.

Regulating the motor speed has the added benefit that it easily accommodates production rises without extra investment, as speed increases of 5–20 percent are not a problem with an AC variable speed drive. By matching the performance of the motor to the needs of the process, variable speed drives can give major savings, compared to the wasteful practice of running the motor at full speed against a restriction to modulate output. In an ideal world, we would be approaching the point where energy was applied with pinpoint accuracy when and where needed, and never wasted.

Despite these obvious energy saving advantages, 97 percent of all motors in applications under 2.2 kW have no form of speed control at all, equating to some 37 million industrial motors sold annually worldwide.

In the past, this might have been understandable, as a small drive cost in the region of US$500 per kW. But over the past few years, drives across the range have become smaller and cheaper, and now start at around US$ 150 per kW. This can make investment in a variable speed drive a viable proposition on energy grounds alone.

The new generation of drives is smaller and so installation might be possible in places where a space constraint was an issue in the past. They are also more energy efficient than their predecessors. An example of these smaller, cheaper drives is the ABB Comp-AC range; these are being used in new, small-scale operations where no one would have thought of employing a variable speed drive in the past, such as potters' wheels, spa baths and oven hobs. By 2002, it is estimated that 40 percent of the value (and 90 percent in units) of all drives shipped will be rated at less than 40 kW.

ABB is leading the way in developing drive technology, with radical new control techniques such as Direct Torque Control (DTC) **4**. A feature of DTC which contributes directly to energy efficiency is motor flux optimization, which greatly improves the efficiency of the total drive, the controller and the motor in pump and fan applications.

The drives themselves are becoming leaner too, not only smaller in size but more energy efficient to manufacture, with smaller circuit boards and enclosures made of recyclable plastic.

ABB drives in use

A case in point is the German company Stadtwerke Strausberg, which operates the district heating scheme in the town of Strausberg, 30 km east of Berlin. Its 86-MW power plant produces 190,000 MWh of heating energy, distributed through a 32-km distribution network with seven substations, to most official buildings and 50 percent of the private households in the town. The company decided to upgrade its control system, which was using throttling valves, to one with variable speed drives.

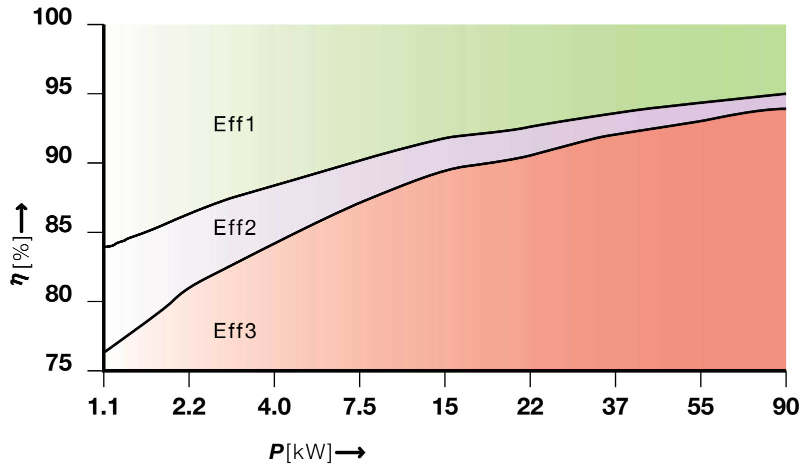
Using the throttling valves to reduce flow increased the head, making the system less efficient as the pump worked harder to overcome the extra head. Temperature changes were too large and fast, and high pressure through the control valves caused loss and noise.

The system is now equipped with variable speed drives, and works on the principle of keeping constant pressure in the network. When temperatures drop, the thermostat valves open, causing the pressure to fall and the pressure transmitter output signal to decrease. This increases the pump speed and the higher flow rate increases the water pressure until a control loop balance is reached.

The annual pumping energy consumption was about 550 MWh using throttling valves, but that was reduced to 230 MWh when variable speed controlled pumps were used throughout the year. The payback period of the variable speed control system was 12 months.

The next step – motor efficiency

The other major energy efficiency strategy is to make the motors themselves more energy efficient and encourage companies to use them.



5 ***The EU has published energy efficiency categories for motors. There are three class levels: Eff1, Eff2 and Eff3, applying to LV two- and four-pole motors rated from 1.1 to 90 kW. The aim is to phase out production of the less energy efficient machines.***

The Danish Energy Agency is one of the leading organizations in this field. It has published a list of high efficiency motors and offers subsidies for motors purchased from this list: 100 Danish Krone per kilowatt for both new plant and for replacements. It promotes this scheme direct to the 4000 largest end users of motors.

The USA and Canada have introduced the Energy Policy and Conservation Act (EPAct). Among other legislation to improve the environment, it specifically targets motors from 0.75 to 150 kW as prime candidates for improvement. It has adopted a scheme similar to the Danish one, with a list of high-efficiency motors published and reduced electricity tariffs for users of these motors.

The US Department of Energy also requires the efficiency rating to be indicated on the motor nameplate, the energy efficiency to be displayed prominently in all literature and marketing material, and the inclusion of other markings to facilitate the enforcement of energy efficiency standards. Failure to comply with these requirements carries severe penalties.

The European Union has also introduced new energy efficiency policies under the SAVE and PACE initiatives. Policies consist of a mix of legislation and voluntary agreements, including mandatory minimum efficiency levels, voluntary agreement of manufacturers, quality marks and incentives.

The EU is also working with CEMEP, the European Committee of Manufacturers of Electrical Machines and Power Electronics, to improve the efficiency of motors. In 1996, the EU Commission unveiled its plans to expand the use of high-efficiency motors, and CEMEP was instructed to work towards making these motors standard. 1999 saw agreement between the EU and CEMEP on efficiency levels for motors. There are three class levels of efficiency, known as Eff1, Eff2 and Eff3, applying to low voltage two- and four-pole motors with ratings between 1.1 and 90 kW **5**.

6 ***ABB was awarded MOTIVA awards for its development of high-efficiency motors.***

Effective from January 1, 2000, the scheme requires motor manufacturers' literature to indicate the Class Level at three-quarter and full load. The motor nameplate also needs to carry confirmation of the Class Level. The intention is to reduce the manufacture of motors in the lowest efficiency Class Level, Eff3, by 50 percent within three years and to zero soon afterwards, at the same time increasing the numbers of motors made in levels Eff1 and Eff2. The scheme will also encourage motor users to use high-efficiency motors exclusively.

There are also various non-legislative initiatives to encourage the development and use of energy efficient motors. An example is the Hi Motors competition run by the MOTIVA Energy Information Center, Finland, in association with the Lappeenranta University of Technology. Its aim was to produce marketable 4-pole motors with losses 25–50 percent lower than average **6**

ABB entered the competition and submitted the 5.5-kW M2AA132 in a category that demanded a mandatory efficiency level of 90.4 percent. ABB's motor achieved 91.0 percent efficiency.

Table 1

Results of tests carried out on 15-kW motors rewound at nine different repair companies

Motor	Efficiency change %
1	– 3.4
2	– 0.9
3	– 0.6
4	– 0.3
5	– 1.0
6	– 0.7
7	– 0.4
8	– 0.9
9	– 1.5
Average	– 1.1

ABB also submitted the 75-kW M2BA280, beating the mandatory level of 95.8 percent with an efficiency of 96.3 percent.

Motor rewinds – a false economy

Many motor users, faced with a failed motor, will opt to have it rewound rather than purchase another one, believing this to be the cheaper of the two options. Although this is the case in a straight comparison between rewind cost and new purchase cost, the resulting loss of efficiency wipes out any initial cost advantage.

This was illustrated in the Ontario Hydro experiment. Ontario Hydro purchased ten new 15-kW motors, which were then independently tested. The motors were then purposefully damaged and sent to nine different repair companies. They were retested after winding, with the results shown in *Table 1*.

Ontario Hydro concluded that, in many cases, failed standard efficiency motors should be scrapped and replaced by high-efficiency models.

Efficiency is lost in rewinds for several reasons: core losses increase due to the high temperatures experienced during failure; stripping the motor for repair also damages the laminations; copper losses increase because of the practice of using smaller conductors, increasing I^2R losses; finally, fitting of universal cooling fans, which may not be designed for the particular motor, leads to an increase in windage losses.

This decrease in efficiency and the consequent increased running cost makes the rewinding of motors not such an attractive option as it might first appear, as *Table 2* illustrates.

As can be seen from the figures, purchasing a new ABB motor results in a saving of USD 690 over the first year.

Table 2

Rewinding a motor versus purchasing a new one
Example: 75-kW 4-pole motor; continuous running; US$0.063/kWh

Original motor rewind	New ABB motor
Cost of rewind: US$ 2226	ABB high-efficiency motor Typical capital cost: US$ 3585
Increased annual cost with 1.1% efficiency loss: US$ 613	Annual energy saving with 3% increase in efficiency: US$ 1435
Actual cost in 1st year: US$ 2840	Actual cost in 1st year: US$ 2150

Improving motor efficiency

What can be done to improve motor efficiency? Designers can minimize losses by improving the design of features that give rise to the main losses in the motor. The greatest losses are the iron losses that occur in the rotor and stator, accounting for 50 percent of the total loss. This can be improved by using low loss steel and thinner laminations. Copper losses account for 20 percent. Using an optimum slot fill design and larger conductors can reduce these. Bearing friction and windage losses total 23 percent and can be reduced by using a smaller cooling fan. Stray losses, which account for 7 percent of the total, can be reduced by improving the slot geometry 7.

Manage your motors

Users can also do a great deal to ensure they are getting the highest efficiency from their motors. A defined motor management policy needs to be in place. One policy decision should be to select high-efficiency motors when purchasing new plant. Users need to specify minimum acceptable efficiency values. A replace or rewind decision can be made long before failure occurs – there need to be clear guidelines for all responsible personnel.

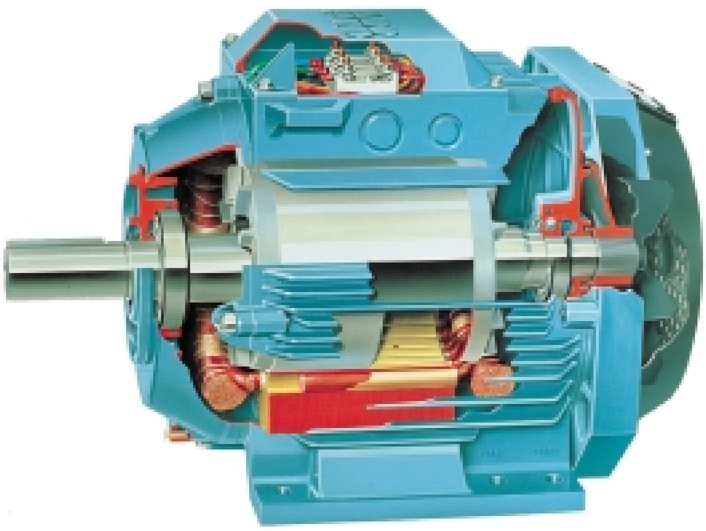
High efficiency also means improved reliability and less downtime and maintenance. Lower losses give:

- Better tolerance to thermal stresses resulting from stalls or frequent starting
- Increased ability to handle overload conditions
- Better resistance to abnormal operating conditions, such as undervoltage and overvoltage or phase unbalance
- Higher tolerance to poorer voltage and current wave shapes

A motor management policy helps bring together capital, maintenance and revenue budgets, showing the effect they have on each other when different types of motors are selected.

Users benefit from such a policy through reduced energy costs, by upgrading to high-efficiency motors at the most cost-effective time. The forward planning inherent in the practice helps reduce downtime and inventory can also be reduced through a fast track delivery agreement.

7 ***Motor efficiency can be increased by improving the laminations, slot geometry and slot fill design, and by using smaller cooling fans and larger conductors.***



The ABB way

What is ABB doing to reduce the negative impact that its motors and drives have on the environment? As well as constantly developing and promoting the use of high-efficiency motors and variable speed drives, ABB maintains a close watch on the total environmental cost of its products. One of the most useful management tools in this area is Life Cycle Assessment (LCA), which assesses and quantifies the environmental impact of products during their entire lifetime – from supply and manufacture to use by customers and disposal of the products.

ABB's corporate Research Centre in Västerås has been working for a number of years to develop methods and capabilities in the field of LCA. ABB, along with several other companies, is supporting efforts to develop objective methods for LCA through participation in the Center for Environmental Assessment of product and Material Systems (CPM) in Gothenburg. CPM's objective is to provide industry with objective LCA methods and to support the integration of environmental protection into all aspects of products and services.

The CPM now verifies ABB's lifecycle assessment data, adding credibility to our LCA process. This is extremely important, since most of the negative impact that ABB has on the environment results from the use of our products. LCA helps ABB ensure that manufacturing, use and disposal of our products has the least possible negative impact on the environment.

A typical product studied using this approach is the ACS 400, part of the Comp-AC variable speed drive range. The environmental impact of the product was studied using LCA with the 'Environmental Priority Strategies in product design' (EPS) method. The product was considered to have a lifetime of ten years, with a usage time of 4000 hours per annum in a 4-kW-pump application in Central Europe. All the categories of environmental impact studied, such as global warming, acidification and toxicity of water, produced negative values for the emissions that contribute to them, showing that using the product reduces the impact of these chemical pollutants (*Table 3*).

Table 4 shows an example of an LCA assessment, a comparison between two standard 15-kW electric motors of different designs running at 12 kW. Motor A is an ABB motor, manufactured at ABB Motors in Västerås. Motor B is made by a competitor. Although motor A requires more copper and iron to manufacture than motor B, this makes motor A more efficient in operation, meaning that it uses less electricity than motor B over its lifetime. With both motors operating 8000 hours

Table 3

Environmental impact of the ACS 400 drive, assuming a lifetime of 10 years and 4000 hours of use per year in a 4-kW pump application

Environmental impact	Amount including energy saved	Equivalent unit
Global warming	– 7310.33	Carbon dioxide, kg
Acidification	– 45.70	Sulfur dioxide, kg
Abiotic depletion	– 25.18	Unit derived from resources use/known resources on Earth ratio
Nutrification	– 1.97	Phosphate emission
Ozone depletion	Not available	CFC-11, kg
Photochemical oxidant formation	– 1.62	Ethylene, kg
Ecotoxicity	– 0.16	Polluted water exposed to toxicologically acceptable limit, m^3
Human toxicity in air	– 64.30	Human body exposed to toxicologically acceptable limit, kg
Human toxicity in water	– 0.07	Human body exposed to toxicologically acceptable limit, kg

per year for 15 years, the following results were obtained.
In motor A, with an efficiency of 91.1 percent, 140,681 kWh will be lost and in motor B, with an efficiency of 89 percent, 177,978 kWh will be lost.

Table 4 shows the environmental aspects of these two motors based on their losses, manufacture and 98 percent recycling. It has been assumed that the motors will run on an average European mix of electricity. The environmental impact of motor B is greater than that of motor A. Evaluated according to the EPS scheme, motor A puts 21 percent less burden on the environment than motor B.

Motors and their efficient speed control are a major environmental issue. They are clearly a major consumer of the world's energy production and are therefore responsible for a large proportion of the pollutants released to the environment through this production. Reducing the energy they waste, through running them at optimum speed for the load by using variable speed drives and making the motors themselves more efficient, can go a long way to reducing this impact.

Companies such as ABB, with their expertise in both technologies, can have a real beneficial effect. ABB is committed to doing what it can to reduce the negative impact of our products on the environment, demonstrated by our adoption of the environmental standard ISO 14001, which helps companies establish and maintain environmental management systems. The environmental department of the Swedish Standards Institution has recognized ABB as being in the forefront of environmental management systems.

For our customers, of course, energy efficiency is not just an environmental issue. It has a real effect on their costs and therefore their profitability and competitiveness. Environmental pressures and sound business economics are driving forward the development of motors and drives, improving the technology for the benefit of all. ■

Table 4

Environmental impact of two standard 12-kW motors of different designs. Motor A is from ABB.

Environmental aspects over full lifecycle	Motor A: 12 kW 91.1% efficiency	Motor B: 12 kW 89% efficiency
Use of resources		
Coal (kg)	16,370	20,690
Gas (kg)	2,070	2,620
Oil (kg)	3,240	4,090
Steel (kg)	27	24
Copper (kg)	0.9	0.8
Aluminium (kg)	4	4
Silicon (kg)	1.1	1.0
Other (kg)	0.09	0.09
Emissions		
Carbon dioxide (kg)	62,940	79,560
Sulfur dioxide (kg)	495	626
Nitrogen dioxide (kg)	136	172
Hydrochloric acid	8.8	11.1
Metals (g)	538	538
Heavy metals (g)	1.1	1.1
Solid waste (kg)	117	106
Particles (kg)	30.4	38.4
Other (kg)	12	15
Total EPS indices	8,260 ELU of which 99.4% from operation	10, 430 of which 99.5% from operation

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